106

DAC-58120

X68-17909

OCEANOGRAPHY AND METEOROLOGY

A SYSTEMS ANALYSIS TO IDENTIFY
ORBITAL RESEARCH REQUIREMENTS

VOLUME I

EXECUTIVE SUMMARY REPORT

ADDENDUM ONE TO A STUDY OF SPENT SATURN IVB
STAGE UTILIZATION FOR SUPPORT OF EARTH ORBITAL
MISSIONS – CONTRACT NO. NAS8-21064

APRIL 1968

DOUGLAS
MISSILE & SPACE SYSTEMS DIVISION

OCEANOGRAPHY AND METEOROLOGY

A SYSTEMS ANALYSIS TO IDENTIFY ORBITAL RESEARCH REQUIREMENTS

VOLUME I
EXECUTIVE SUMMARY REPORT

APRIL 1968 DAC-58120

Presented to:
National Aeronautics and Space Administration
Marshall Space Flight Center
Manned Spacecraft Center
Contract No. NAS 8-21064, Addendum One

NASA Program Management:
Edward H. Olling, MSC – NASA Study Manager
Ernest E. Kennedy, MSC – Study Technical Director
James F. Madewell, MSFC – Contracting Officer's Representative
William R. Perry, MSFC – Study Technical Monitor
Charles A. Huebner, OMSF – Chief, Mission Planning

Prepared by:
W.W. Hildreth, A.B. Hollinden, M. Weinstein
F.H. Shepphird
Study Manager
Douglas Missile and Space Systems Division

Approved by:
H.L. Wolbers
Program Manager
T.J. Gordon
Director
Advance Launch and Space Systems
Douglas Missile and Space Systems Division

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

PREFACE

This report is submitted to the National Aeronautics and Space Administration (NASA) by the Missile and Space Systems Division (MSSD), Douglas Aircraft Company, a component of the McDonnell Douglas Corporation. It was prepared under Addendum One, Contract No. NAS8-21064. The purpose of this addendum was to explore the disciplines of oceanography and meteorology and to identify those elements of a long-range research plan which could be effectively accomplished with manned space platforms.

This report is in two parts: Volume I is an executive summary of study results and conclusions. Volume II contains the technical details of the analysis.

Using an analytic approach developed on an earlier study (NAS8-21023) the present effort has attempted to identify the orbital observational requirements needed to support key research objectives in oceanography and meteorology. Scientific research objectives, as well as the socioeconomic and political factors which in turn may dictate knowledge requirements in these areas, have been considered. The study was conducted in accordance with the NASA-approved Program Study Outline, dated 27 June 1967.

Requests for further information concerning this report are invited and will be welcomed by:

- Edward H. Olling, Code ET-4
  Chief--Earth Orbital Mission Office
  National Aeronautics and Space Administration
  Manned Spacecraft Center
  Houston, Texas 77058
  Telephone: 713-483-4966

ACKNOWLEDGEMENT

During this study, the Douglas Aircraft Company was provided guidance and assistance by key members of the academic community. These eminent scientists, as members of the study team, served in the capacity of contributing consultants and are listed below in alphabetical order.

Konrad J. K. Buettner, Ph. D.
Professor of Meteorology
Department of Meteorology
Univeristy of Washington
Seattle, Washington

Tetsuya Fujita, Ph. D.
Director
Mesometeorology Research
Department of Meteorology
University of Chicago
Chicago, Illinois

Richard A. Geyer, Ph. D.
Head
Department of Oceanography
Texas A&M College
College Station, Texas

Charles L. Hosler, Ph. D.
Dean
College of Earth and Mineral Sciences
Pennsylvania State University
University Park, Pennsylvania

Edward D. McAlister, Ph. D.
Director
Applied Oceanography Group
Scripps Institution of Oceanography
La Jolla, California

Yale Mintz, Ph. D.
Head
Department of Meteorology
University of California at Los Angeles
Los Angeles, California

John D. H. Strickland, Ph. D.
Head
Institute of Marine Resources
Food Chain Research Group
Scripps Institution of Oceanography
La Jolla, California

Verner E. Suomi, Ph. D.
Director
Space Science and Engineering Center
University of Wisconsin
Madison, Wisconsin

Although responsibility for any errors or omissions that have occurred in this study must be borne by Douglas, credit for its merits must be shared with the above scientists and the many other persons whose input was derived from their publications in the scientific literature and in such survey documents as "Oceanography from Space" published by the Woods Hole Oceanographic Institution. All of these contributions are gratefully acknowledged.

STUDY TEAM TECHNICAL STAFF

The following Douglas Missile and Space Systems Division personnel, listed alphabetically, supplied major technical contributions to this study:

Mr. R. W. Allen, Senior Systems Engineer (1)
Mr. T. J. Gordon, Director (2)
Dr. W. W. Hildreth, Chief Scientist (3)
Mr. A. B. Hollinden, Senior Research Scientist--Meteorology (3)
Mr. F. D. Riel, Senior Systems Engineer (2)
Mr. F. C. Runge, Program Manager (2)
Mr. F. H. Shepphird, Project Manager (2)
Mr. V. A. Sirounian, Senior Research Scientist--Space Physics (3)
Mr. J. Tillman, Senior Instrumentation Engineer (3)
Mr. M. Weinstein, Senior Research Scientist--Meteorology (3)
Dr. H. L. Wolbers, Program Manager (2)

(1) Aerospace Systems Analysis Directorate

(2) Advance Space and Launch Systems Directorate

(3) Research and Development Space Sciences Department

Besides the specific individuals listed above, the services were utilized of Oceanography Research, San Diego, California. The contributors from that organization were as follows:

Dr. Paul M. Maughan, Project Manager
Mr. Joseph W. Joy, Research Oceanographer
Dr. Joseph M. Colonell, Research Engineer
Mr. Richard H. Greenbaum, Oceanographer
Mr. Hobart H. Steely, Meteorologist

CONTENTS

FIGURES

TABLES

Section 1

INTRODUCTION AND SUMMARY

For specific applications, the technological capability required to utilize the vantage point of space to learn more about the Earth's land masses, atmosphere, and oceans, is now available. The unmanned satellites of the Environmental Sciences Service Administration are transmitting routine weather data on a global basis. NASA's development and instrument feasibility programs, including Nimbus and the Applications Technology Satellites (ATS), are providing vital scientific data which will amplify our knowledge of the new mechanisms of space utilization. The ATS III carries an experiment developed by V. E. Suomi* and R. J. Parent, in which a "spin-scan" camera system views one-third of the globe from a geostationary orbit (Figure 1-1). Using three photomultiplier circuits, this camera completes a new three-color picture every 30 min. during daylight periods. These color presentations show the contrasting features of the clouds, land, and the oceans and have already suggested new concepts of tropical circulatory patterns. This program can lead to the development of an operational system which will provide almost continuous cloud-coverage data and enable meteorologists to follow changes in global weather conditions on a nearly real-time basis. As an example, it has already been possible to estimate average winds from these pictures by recording the movement of discrete cloud cells.

Equally exciting has been the experience gained with manned space flight. Pictures taken from space by the astronauts with hand held cameras have provided a wealth of photographic material on the spectral reflectance characteristics of clouds, land, and water. Figure 1-2 from Gemini IV graphically illustrates the feasibility of recording sun glint or solar reflection from the sea surface. By measuring the extent and breadth of the sun glint area from space, surface wind conditions and the sea state can be estimated. Wave patterns are also discernible in similar photographs. These early applications appear so encouraging and promise such large economic return when embodied in operational systems that initial planning of more extensive programs appears warranted. **

While the opportunities for important research from a platform in Earth orbit are clear, significant planning questions remain for NASA. For example, the design of the space station or satellite and its scientific instrumentation may be extremely sensitive to the continuously evolving objectives of the research program. What is their sensitivity to research objectives? What are acceptable strategies in reaching these objectives? Considering the real-life constraints of physical and intellectual resources, is there a systematic approach to planning for the accomplishment of these objectives?

In a sense, the ultimate objective of this study was to reduce the uncertainty in the planning of orbital research and development and operational programs in the disciplines of oceanography and meteorology.

The specific purpose of this study was to identify and analyze elements of a long-range evolutionary plan which would capitalize on the contributions of manned space flight and exploit the orbital opportunities offered to oceanography and meteorology. Douglas sought to design the program in a way which would satisfy the needs of the scientific community to as large an extent as possible, with flexibility for change as new data about the oceans and the atmosphere stimulated new objectives. In identifying the critical research objectives of these disciplines, the study team sought to apply a planning methodology which would demonstrate the completeness

*A consultant to Douglas on the present study.
**For example, see Reference 1.

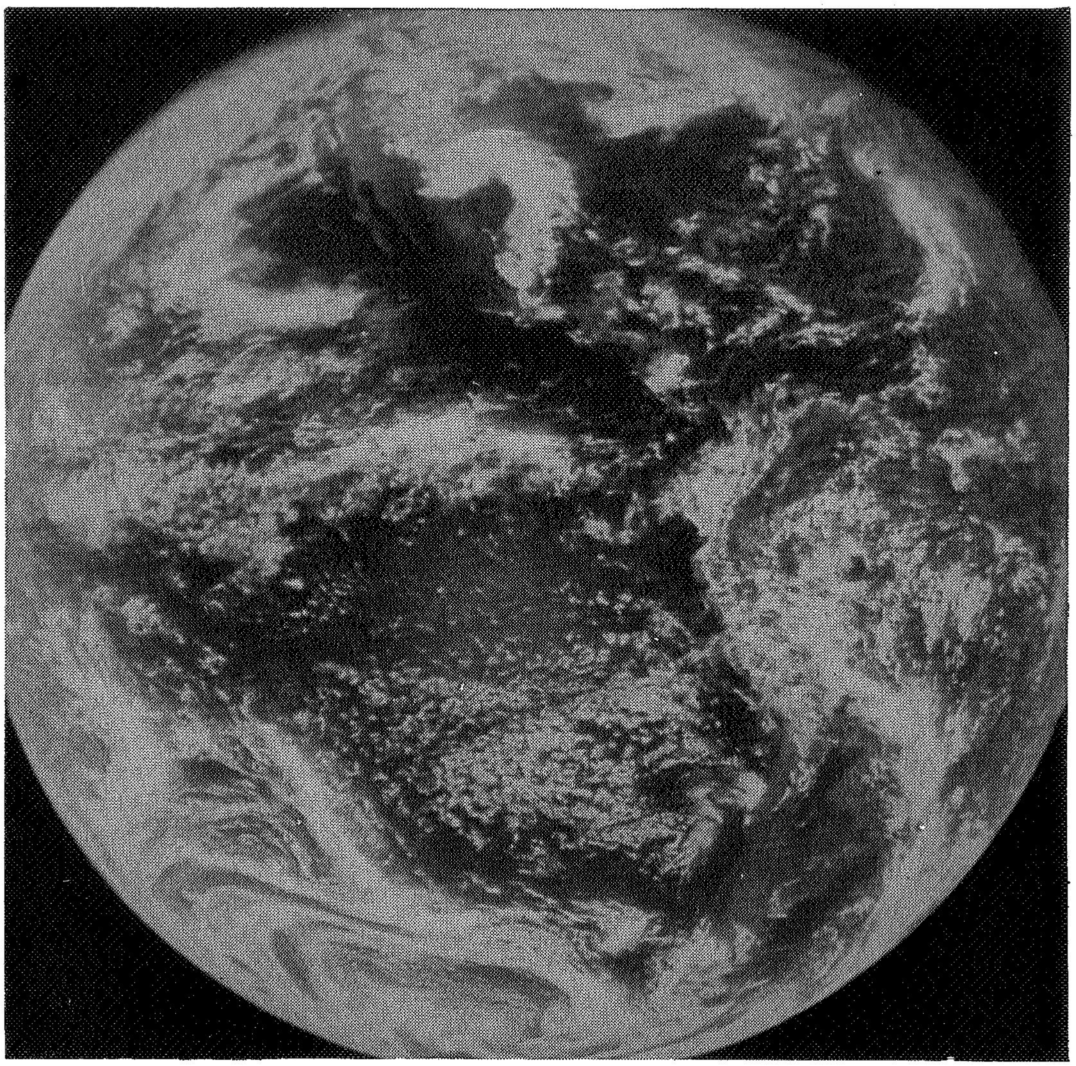

Figure 1-1. Earth From a Geostationary Orbit

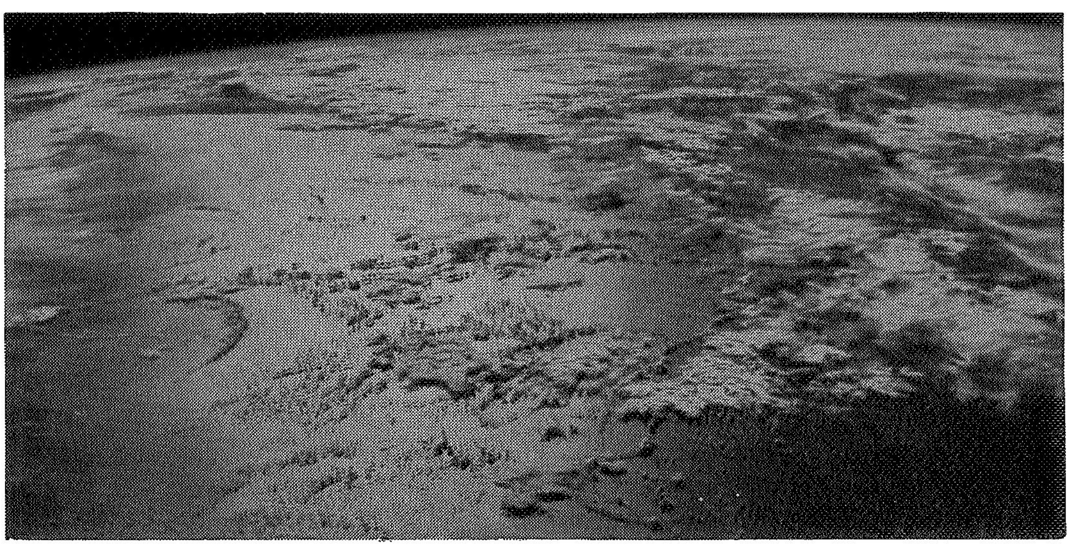

Figure 1-2. Solar Reflection From the Sea Surface

of the program and yield information as to relative priority ranking among the space experiments. The methodological approach used had been developed partially in an earlier Orbital Astronomy Support Facility (OASF) Study, (References 2 through 5) conducted by Douglas.

The Orbital Oceanography and Meteorology Study was limited to the sun-Earth relationships within the boundary shown in Figure 1-3. Specifically, the study considered the ocean, the atmosphere, and certain of their interactions with the land. Included were the coastal-zone effects and the tidal influence of the moon. The air-sea interface with land areas, the freshwater or limnological zone, and the sun's and moon's tidal effects on the atmosphere, although prime candidates for future research, were not explored in this study.

Examining oceanography and meteorology through the eyes of both the research scientist and potential users of the information led to the identification of a number of critical issues, which included, for example, the detection and identification of edible fish and sea plants from orbit; the use of the sea as a source of energy and as a depository for effluent outfall and other wastes; the accretion rates of sediment and sand; the causes of air pollution, and their impact on climatic conditions and the heat transfer mechanisms affecting macro, meso, and micro climatic effects. In recognition that many of the implied measurements cannot be made from a remote platform, the study initially identified those areas where remote sensing was currently possible or was desirable.

Sixty-four such measurement areas were identified. Five of these appeared to require instrumentation beyond the state of current knowledge and theory; for example, the remote measurement of sea surface charge. Of the remainder, all appeared feasible from orbital platforms operating independently or in conjunction with aircraft or surface stations. It was found that a significant number (about 30%)

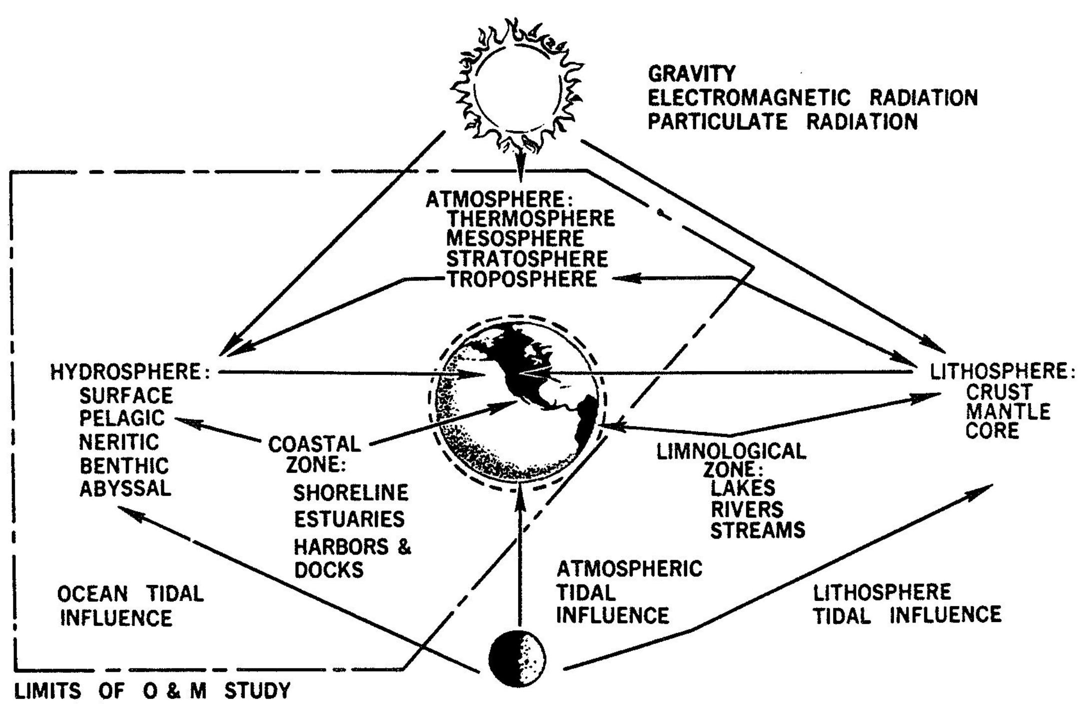

Figure 1-3. Sun-Earth Relationship

of the measurement techniques could be developed using aircraft alone; less than 10% of the R&D measurements required orbital testing alone. The "orbital-only" instrumentation was primarily associated with utilization of zero gravity; for example, in cloud chamber and weather-modification experiments. By far more common (60%) was the need for multiple platforms. This type of sensor development involved the comparison of data obtained by remote monitoring with data obtained at the source; for example, correlating remote microwave radiometric measurements with sea-surface temperature measurements made from surface vessels.

Although the detailed definition of the role of man in orbital research was beyond the scope of the present study, a preliminary analysis indicated that considerable value could be attached to his presence during the initial research and instrument development phases of the orbital operations.

To provide a basis for sequencing the tasks which should be accomplished in an orbital program, value judgments of the detailed objectives were made by the scientific contributors. The study has shown that a composite list of basic measurements can be formulated which is relatively insensitive to differing opinions of worth, yet is relatively responsive to the needs of potential users.

Section 2
STUDY OBJECTIVES

The objective of this study was to systematically identify, for program planners, those research objectives and measurements in the fields of oceanography and meteorology which could profitably exploit the potential offered by manned orbital facilities.

The managers and decision makers responsible for guiding this nation's space program are continually faced with alternative courses of action. In the selection process, a choice is made from among these alternatives which affects the allocation of resources, the implementation and scheduling of programs, and the determination of costs and potential benefits. The information needed by management to develop decision criteria is essentially the same regardless of the scientific or technical area of interest. Research objectives must be defined, an orbital experiment program must be generated, supporting research and development (R&D) requirements must be identified, the facility requirements must be specified, and the ground support and operational interfaces must be determined (Figure 2-1). For each of the hardware items involved, development times and costs must be estimated to provide a master time-phased program bounded by realistic projections of budgetary limits. When planning information is available in this form, management will be in a more tenable position to weigh and decide among the many competing demands for resources.

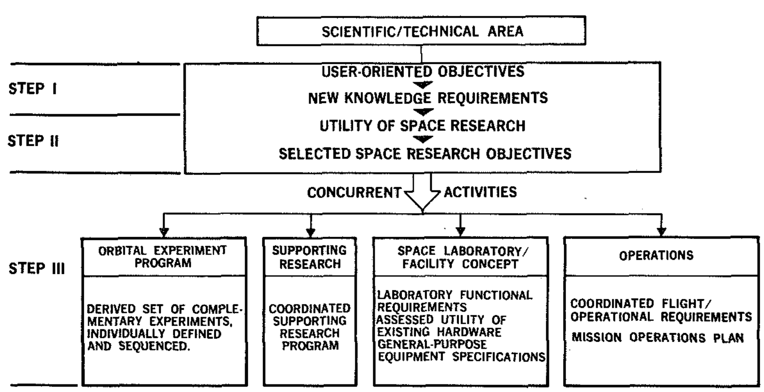

Figure 2-1. Requirements Analysis

In attempting to assess the impact on, and conversely to evaluate the potential provided by, manned orbital facilities in any area of research, it would appear that three steps are required: Step I, identification of critical issues or significant research objectives; Step II, examination of the utility of space and the selection of those specific research objectives for which space-based measurements offer unique information; and Step III, development of an orbital experiment program which details the instrumentation, facility, and operational support required.

The systems approach to program definition involves all three steps. The present study was concerned only with Steps I and II. Of particular interest was the identification of those research areas where manned space platforms could offer unique capability. The results of this study provide much of the basic information needed for NASA to proceed to Step III, the next phase of the total program definition activity.

The study team was aware that in scientific disciplines, unexpected rather than planned events sometimes contribute most significantly to scientific insight and that such unexpected discoveries could well influence subsequent planning. Furthermore, while rigid research plans may facilitate the design of space instruments, they may stifle innovative research. Recognizing these aspects, the study team sought to develop an approach that would provide a consensus structured well enough for initial planning and for the derivation of instrument and space-station designs, but flexible enough to permit change and individual contributions and participation.

Section 3

RELATIONSHIP TO OTHER NASA EFFORTS

Several recently completed advanced system studies have examined the broad spectrum of potential space-research activities. These activities include those related to the basic sciences; Earth-resource surveys, and such applied problems as the potential provided for communication, navigation, and traffic control (References 6 through 18). Although these activities have served to provide insight into the wealth of research capability provided by the utilization of space platforms, relatively few studies have attempted to define in detail a specific research program or the implementation requirements for accomplishing such a program.

A notable example of the approach required for program planning in each scientific area is the OASF Study recently completed for the Marshall Space Flight Center (MSFC). In that study, a basic methodology for the systematic analysis of astronomy research objectives and their attendant measurement and mission requirements was developed. While the oceanography and meteorology requirements study described in this document did not have as its immediate objective the accomplishment of the same depth of program planning acitivity as encompassed by the OASF Study, it was nevertheless possible to profit directly from the methodological approach to requirements analysis developed in the latter. In addition to the OASF Study, many of the recent studies in oceanography and meteorology sponsored by NASA and other government agencies provided valuable insights into the critical problems identified by oceanographers and atmospheric scientists and were used extensively as background material for the present study. Of special note are the activities of the Spacecraft Oceanography Project sponsored by the U. S. Naval Oceanographic Office, the activities of the Committee on Atmospheric Sciences, COSPAR, and the World Meteorological Organization.

Section 4

STUDY APPROACH

In identifying key research objectives and selecting those which can most profitably be addressed from manned space platforms, the systems engineer is faced with the problem of assuring himself that he has in fact considered all relevant areas, i.e., that there are no significant gaps in his coverage. In addition to demonstrating completeness, a research-oriented plan should also inherently contain information from which relative priority among competing measurements can be assessed. Similar considerations were addressed in the NASA OASF Study performed by Douglas, and a methodology was developed which was found to be generally applicable to the oceanography and meteorology case. Briefly, four methods of analysis were investigated: an "object-oriented" approach, based on the system described by Churchman, Ackoff, and Arnoff (Reference 19); a morphological or "parametric-matrix" approach patterned after Zwicky's work, in which such particular parameters of interest as angular resolution, spectral bands, etc., were related to the astronomical bodies (Reference 20); a "consensus approach" to define "burning issues" of astronomy (Reference 21); and finally a "research-oriented relevance tree." This final approach differed from the earlier concepts in that it recognized the necessity of articulating the relationship between the theoretical and the experimental branches of the discipline. In effect, the earlier methods yielded only a systematic cataloging of potential experiments and observations with little cohesive structure to indicate logical relationships among experiments. This missing intrastructure connects the theories, the hypotheses, and the experimental programs which evolve from them. The theoretical portion of the research-oriented approach consisted of statements of the alternative research hypotheses. The experimental branch consisted of a spectrum of potentially feasible experiments within the limits set by currently held views of the discipline. Clearly, there is an adaptive feedback in which new or unexpected experimental data cause theory revision and revised theories suggest new experimental domains. This is illustrated in Figure 4-1.

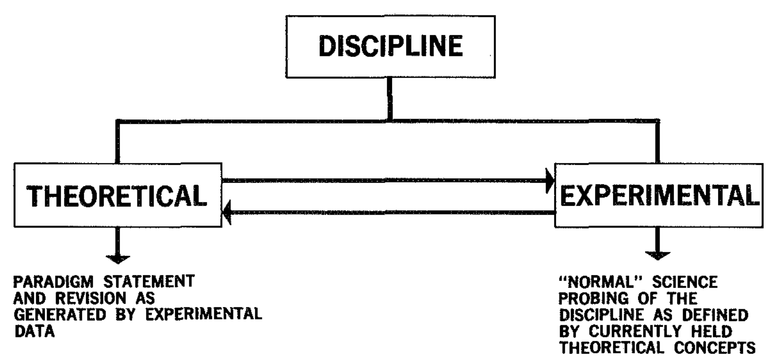

Figure 4-1. Element Feedback

Douglas applied this model to astronomy, labeling the theoretical model-building aspects: "definition of the origin and future of the universe" (evolution) and "establishment of principles of change and order of the universe" (laws). The experimental branch was called "observation of the present state of the universe." This breakdown served as the top level of our final relevance-tree format and was used in the form shown in Figure 4-2.

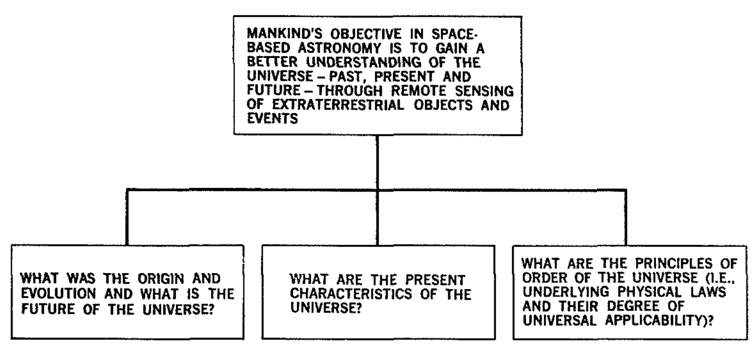

Figure 4-2. User-Oriented Objective Approach-Astronomy/Astrophysics

These three categories represent three points of departure for the discipline. Taken together, they fully define its present state of knowledge and are capable of being expanded to include new knowledge as it is collected. The division among these points of departure is coincident with the contemporary sub-disciplines of astronomy: cosmology and cosmogony, observational astronomy, and astrophysics. This breakdown of evolution, state, and laws of order apparently has general application to relevance-tree structuring of many other scientific disciplines (Figure 4-3).

In view of the success of this research-oriented approach in the OASF Study, it was believed that a similar type analysis could be of value in identifying the measurement requirements of significance to orbital oceanography and meteorology. Whereas astronomy asks questions pertaining to understanding the universe, oceanography and meteorology ask questions pertaining to the oceans and the atmosphere. In this sense, a direct parallel did appear for the categories identified as evolution, state, and change. In meteorology, questions of evolution lead to consideration of the Molten-Globe Hypothesis, the Accretion Hypothesis, the Original Component Hypothesis, and others. Questions of physical laws of change lead to consideration of the factors of momentum, heat, mass, and chemical composition. Observational factors of the current state of the atmosphere provide a basis for describing and forecasting weather conditions. In a similar vein, oceanographic research objectives also appeared related to evolution (biota, water origination theories, etc.); state (salinity fields, electric, acoustic, and heat flow, etc.); and physical change (erosion principles, sedimentation dynamics, turbulence, and flux relationships).

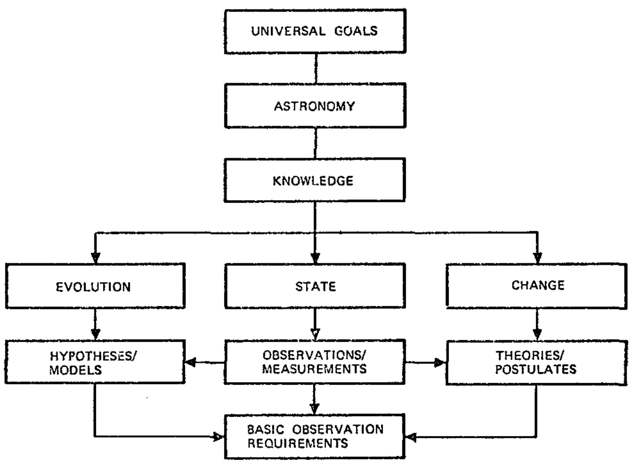

Figure 4-3. Research-Oriented Logic

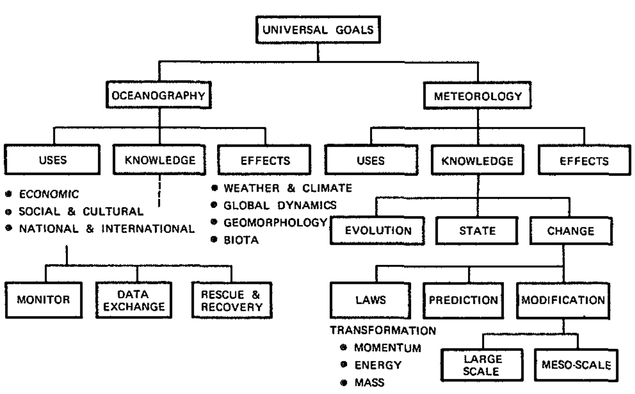

Figure 4-4. O&M Study

While this type of categorization provided an interesting and useful starting point for the more basic sciences, it was found to be somewhat limited for the applied areas. In oceanography and meteorology in particular, it was evident that the analysis should not be limited solely to the scientific goals of the pursuit of knowledge, but should be expanded to consider the uses to which that knowledge could be placed and the effects which oceanographic and meteorological phenomena might have on man (Figure 4-4). Accordingly, the points of departure taken to identify critical issues in this study included the social, cultural, economic, and political uses of the oceans and the atmosphere, and the climatological and geomorphological effects the oceans and the atmosphere would have on biota in general. Using these varied points of departure, it was believed that the resultant identification and listing of measurements which could profitably be made from remote-sensing platforms would be comprehensive and complete.

The final form of the analysis could be described as a logic net or research relevance tree, in which a series of questions could be asked, starting with the broadest categories at the top and deriving at each subsequent level a greater degree of specification until, at the lowest levels, the critical issues pertinent to each major objective area were identified. As an example (Figure 4-5), five levels of increasing detail or specificity were utilized, ranging from General Objectives to Critical Issues. For the three specific categories identified as uses, knowledge, and effects (Figure 4-6), 10 application areas were identified in oceanography and 9 in meteorology; 38 specific categories in oceanography and 37 in meteorology; and 176 critical issues in oceanography and 137 in meteorology. The details of this analysis are presented in Section 3 of Volume II of this Study.

Once the critical issues had been identified in each area, the types of information or knowledge needed to address these issues were determined judgmentally. At this point in the analysis, it was found that a single bit of information or knowledge requirement might be applicable to several critical issues. In the same fashion, some potential measurements were found to provide data applicable to more than one knowledge requirement. As an example, information on the sea-surface temperature distribution would be an important factor in understanding the population dynamics of plankton and would also be important in determining surface-current distribution and upwelling effects. These latter factors in turn affect the distribution of organic and inorganic materials. A direct measurement of sea-surface temperature using IR or microwave radiometry would not only provide information on temperature distribution, but would also be useful in providing information on slicks, surface winds, ocean currents, etc.

To record these interrelationships, the knowledge requirements, critical issues, and measurements were tabulated in a matrix format and are summarized in Tables 4-1 through 4-4. These tables include those critical issues which were identified in the analysis as areas in which remote measurements could offer significant advantages. The derivation of these tables is described in greater detail in Volume II, Technical Report, Section 3.

It was recognized that not each of the knowledge requirements was of equal importance in pursuing each critical issue, and each measurement was not equal in its contribution to the generation of the information or knowledge requirements. With the help of the scientific contributors, consensus judgments of the relative importance of each relationship were made. In their ranking, a value of 10 was used to indicate that the measurement was essential; 5 if it provided only a portion of the desired information; and 2 if it was supplemental data, useful for purposes of interpretation but not a direct indicator of the phenomena of interest. A measurement of sea-surface temperature, for example, would be an essential indicator of temperature distribution (rated 10) but it would only be one contributory bit of data in locating surface slicks (rated 5). Photographic recording may not provide precise surface temperature data, but it would provide supplementary information useful in interpreting IR and microwave patterns if clouds were in the field of view (rated 2). In addition to showing the association of measurements, knowledge requirements, and critical issues, the numbers in the cells of Tables 4-1 to 4-4 indicate the relative degree of importance of the relationship.

When the commonality analysis of measurement requirements was completed, and those measurements feasible or desirable from a remote platform were identified, 35 measurements of importance to oceanography and 29 measurements of importance to meteorology remained. Of these 64 measurements, 11 were common to both oceanography and meteorology. For each of the 64 measurements, an

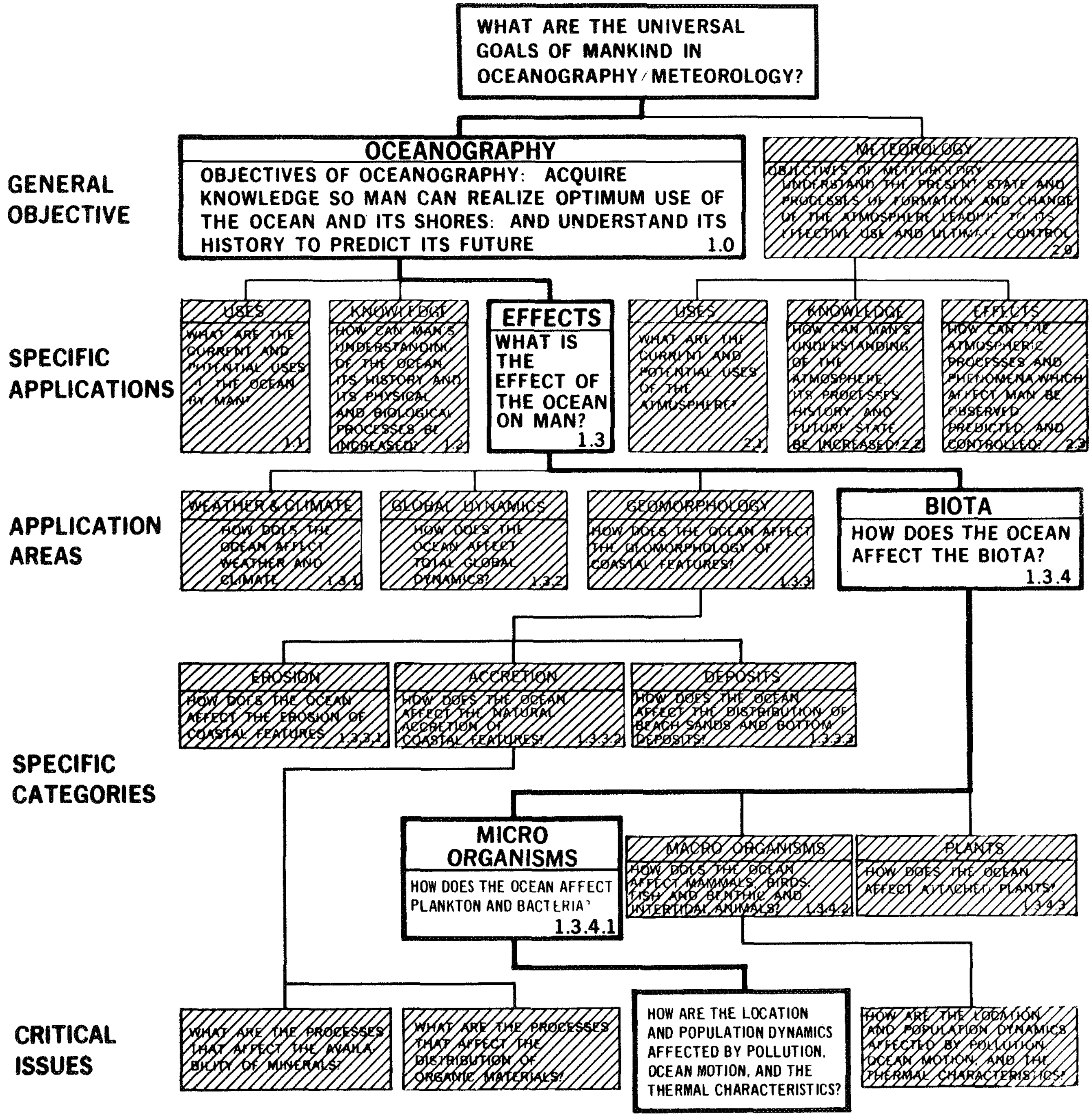

Figure 4-5. Systems Analysis Logic Flow

observation requirement data sheet (ORDS, Figure 4-7) was filled out, specifying the pertinent information regarding such parameters as spectral regions, spatial and temporal resolution requirements, and orbital requirements.

The compilation of ORDS represented the completion of Steps I and II in the program-planning process outlined in Figure 2-1. Specifically, the ORDS (see Volume II) documented those basic measurements which would provide unique information to the disciplines of oceanography and meteorology if the measurement were made from space-based observation platforms.

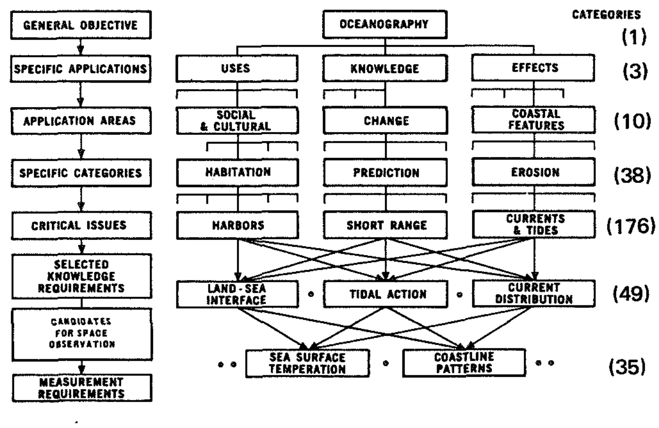

Figure 4-6. Structured Analysis Levels

OCEANOGRAPHY/METEOROLOGY EXPERIMENT SYSTEMS ANALYSIS
OBSERVATION REQUIREMENT DATA SHEET (ORD)

OBSERVATION TITLE (Complete title of parameter measurement requirement)
1. PARAMETER (Lists reference number and brief title.) DATE (Generated) INVESTIGATOR (principal(s))
2. SELECTED KNOWLEDGE REQUIREMENT (SKR) (Contains reference numbers of related KR's
3. OBJECT(S) OBSERVED OR SOURCES (Sites of phenomena)
4. GENERAL EXPERIMENT RELATING PARAMETER TO AREA OF APPLICATION (Describes theoretical basis for observing parameter and indicative models)
5. PARAMETER MEASUREMENT TECHNIQUE (presents suggested feasible sensing method(s))
6. POTENTIAL MEASUREMENT LOCATIONS OR PLATFORMS (ENCIRCLE ONE OR MORE): SURFACE AIRCRAFT ROCKET SPACECRAFT BALLOON BUOY OTHER
7. RELATED OR CONCURRENT OBSERVATIONS, INCLUDING GROUND TRUTH REQUIREMENTS (lists needs for other measurements for interpretation of basic measurement
8. RELATED OR CONCURRENT EXPERIMENTAL AND THEORETICAL WORK lists additional theoretical and model development needs)

PARAMETER OBSERVATION DATA REQUIREMENTS (ITEMS 9-11)

9. PARAMETER QUANTITATIVE CHARACTERISTICS
RANGE , RESOLUTION ,
ACCURACY PRECISION
10. PARAMETER SPATIAL CHARACTERISTICS
RESOLUTION: x , y , z
OBSERVATION HEIGHT OTHER
ACCURACY: x , y , z ,
OTHER
*FIELD OF VIEW: x , y Range z ,
OR SCAN RANGE: θ φ
COMMENTS
*11. PARAMETER TEMPORAL CHARACTERISTICS
CONTINUOUS: RESOLUTION LENGTH
INTERMITTENT: RESOLUTION LENGTH
INTERVAL: MIN. MAX.
EPOCH NO. OF SAMPLES
TIMING ACCURACY: RELATIVE ABSOLUTE

SPECIFIC MEASUREMENT REQUIREMENTS (ITEMS 12-17)

12. MEASUREMENT: RADIATION , FIELDS ,
PARTICLES
13. OBSERVATION TYPE (ENCIRCLE ONE OR MORE): ACTIVE
PASSIVE SURVEY TARGETING PHOTOGRAPHY
SPECTROSCOPY RADIOMETRY POLARIMETRY
IMAGING SCANNING OTHER
14. DETECTOR AND/OR SOURCE TYPE:
INSTRUMENT NAME
15. WAVELENGTHS: RANGE
CONTINUOUS BAND(S): RESOLUTION
*16. ENERGY OR FIELD: RANGE PRECISION
RESOLUTION ACCURACY
* 17. FIELD OF VIEW: x , y ,
RANGE z
RESOLUTION: x , y , z
ACCURACY: x , y , z

DATA PROCESSING REQUIREMENTS (ITEMS 18-23)

18. NO. VARIABLES MIN. INTERVAL
RESOLUTION (%) LENGTH
* 19. DATA STORAGE FORMAT
* 20. ONBOARD DATA PROCESSING
21. NUMBER OF OBSERVATIONS (frequency requirements)
22. DATA RECOVERY MODE AND CHARACTERISTICS
* 23. GROUND DATA PROCESSING

MISSION ORBITAL REQUIREMENTS (ITEMS 24-32)

24. REPEATABLE ORBIT TRACE FREQUENCY
25. ORBITAL INCLINATION n.mi., ±
26. PERIGEE ALTITUDE n.mi., ±
27. APOGEE ALTITUDE n.mi., ±
28. OTHER ORBITAL PARAMETERS
* 29. POINTING ACCURACY ±
* 30. GUIDANCE STABILITY ±
PERIOD
31. MISSION ORBITAL ALTERNATIVES
32. MISCELLANEOUS (explanatory and qualifying notes)

* Items not analyzed in this study but are dependent on the detailed results of an instrumentation and system optimization engineering design study

SAMPLE

Figure 4-7. Observation/Measurement Requirements

Table 4-1
MATRIX OF APPLICATION (Oceanography)

RELATIVE SCALE OF APPLICABILITY
LEGEND:
10-HIGH 5- 2-LOW

Column groups: CRITICAL ISSUES; ECONOMIC USES; SOCIAL AND CULTURAL USES; NATIONAL AND INTERNATIONAL USES; KNOWLEDGE OF EVOLUTION; KNOWLEDGE OF STATE; KNOWLEDGE OF CHANGE; EFFECTS ON WEATHER AND CLIMATE; EFFECTS ON DYNAMICS; EFFECTS ON GEOMORPHOLOGY; EFFECTS ON BIOTA

No.	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	Ratings (left to right)	Count	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	NO.
01	DETERMINE FISH POPULATION DISTRIBUTION	10, 5, 5, 10, 2, 2, 10, 10, 10, 10, 10, 10	11	DETERMINE FISH POPULATION DISTRIBUTION	01
02	DETERMINE OCEAN BIOTA (POPULATION DYNAMICS)	10, 5, 10, 2, 5, 2, 5, 5, 10, 10, 10, 5, 5, 10, 5, 5, 10, 10, 10, 10, 10	22	DETERMINE OCEAN BIOTA (POPULATION DYNAMICS)	02
03	DETERMINE AREAS OF USEFUL TIDAL ACTION	5, 2, 2, 5, 2, 5, 2, 10, 10, 2, 2, 10, 2, 5, 5, 10, 10, 5, 5, 5	20	DETERMINE AREAS OF USEFUL TIDAL ACTION	03
04	DETERMINE OCEAN CURRENT DISTRIBUTION	2, 2, 2, 5, 5, 2, 2, 2, 2, 5, 5, 5, 2, 5, 2, 2, 5, 5, 5, 5, 10, 5, 10, 10, 10, 10, 5, 5, 5, 5	32	DETERMINE OCEAN CURRENT DISTRIBUTION	04
05	DETERMINE OCEAN SURFACE ROUGHNESS (SEA STATE)	2, 5, 10, 2, 2, 5, 2, 2, 5, 5, 5, 2, 5, 2, 5, 10, 2, 10, 10	19	DETERMINE OCEAN SURFACE ROUGHNESS (SEA STATE)	05
06	PREDICT WAVE CHARACTERISTICS	2, 10, 2, 5	4	PREDICT WAVE CHARACTERISTICS	06
07	DETERMINE NEAR SURFACE WIND DISTRIBUTION	2, 2, 5, 5, 2, 2, 5, 10, 5, 10, 2, 2, 2, 2, 5, 5	16	DETERMINE NEAR SURFACE WIND DISTRIBUTION	07
08	PREDICT SEA SURFACE WINDS	5, 2, 2	3	PREDICT SEA SURFACE WINDS	08
09	DETERMINE AREAS OF UPWELLING	5, 2, 2, 2, 2, 5, 5, 2, 2, 2, 2, 2, 5	13	DETERMINE AREAS OF UPWELLING	09
10	DETERMINE ENERGY EXCHANGE ACROSS THE AIR/SEA INTERFACE	5, 2, 10, 5, 5, 5	6	DETERMINE ENERGY EXCHANGE ACROSS THE AIR/SEA INTERFACE	10
11	DETERMINE MOMENTUM FLUX AT THE AIR/SEA INTERFACE	2, 5, 5, 5, 5, 5, 5, 10, 10, 10	10	DETERMINE MOMENTUM FLUX AT THE AIR/SEA INTERFACE	11
12	DETERMINE AREAS OF CONVERGENCE OR DIVERGENCE	2, 2, 2, 5, 5, 2, 2, 2, 2	9	DETERMINE AREAS OF CONVERGENCE OR DIVERGENCE	12
13	DETERMINE CHANGES IN MEAN SEA HEIGHT	2, 5, 5, 2, 2	5	DETERMINE CHANGES IN MEAN SEA HEIGHT	13
14	MONITOR LAND EROSION/ACCRETION AT THE LAND/SEA INTERFACE	2, 2, 5, 5, 5, 5, 2, 10, 5, 10, 10	11	MONITOR LAND EROSION/ACCRETION AT THE LAND/SEA INTERFACE	14
15	DETERMINE AREAS OF POTENTIAL TURBIDITY CURRENTS	2, 2, 2, 5, 5, 2, 2, 2	8	DETERMINE AREAS OF POTENTIAL TURBIDITY CURRENTS	15
16	DETERMINE BREAKER AND SURF CHARACTERISTICS	5, 2, 2, 5, 10, 5, 2, 2, 2, 5, 5, 5, 5, 5, 2	15	DETERMINE BREAKER AND SURF CHARACTERISTICS	16
17	DETECT AND MONITOR TSUNAMIS	10, 10	2	DETECT AND MONITOR TSUNAMIS	17
18	DETERMINE INTERNAL WAVE CHARACTERISTICS	2, 2, 5, 5, 2, 2, 5, 5, 2, 5, 5, 10, 5, 2, 5, 5, 5	17	DETERMINE INTERNAL WAVE CHARACTERISTICS	18
19	DETERMINE BOTTOM TOPOGRAPHY	2, 2, 2, 2, 2, 2, 5, 2, 5, 5, 10, 5, 2, 5, 5, 5	16	DETERMINE BOTTOM TOPOGRAPHY	19
20	LOCATE OIL & MINERALS	10, 10, 5	3	LOCATE OIL & MINERALS	20
21	DETERMINE DISTRIBUTION OF OCEAN SURFACE CHARGE	2, 2, 2, 5, 10, 10, 10	7	DETERMINE DISTRIBUTION OF OCEAN SURFACE CHARGE	21
22	DETERMINE WATER COLUMN STABILITY	2, 5, 5, 5, 2, 5, 2, 10, 5, 5, 2, 2, 2, 2	14	DETERMINE WATER COLUMN STABILITY	22
23	DETERMINE SUBMARINE VOLCANO ACTIVITY	2, 5, 2, 2, 2, 10, 2, 2, 2	9	DETERMINE SUBMARINE VOLCANO ACTIVITY	23
24	DETERMINE HEAT FLOW ACROSS THE AIR/SEA INTERFACE	2, 2, 5, 5, 5, 10, 5, 5, 10, 10, 10, 10	12	DETERMINE HEAT FLOW ACROSS THE AIR/SEA INTERFACE	24
25	DETERMINE LOWER ATMOSPHERE STABILITY	2, 2, 5, 5, 5, 5, 5, 2	8	DETERMINE LOWER ATMOSPHERE STABILITY	25
26	MONITOR CLOUD PATTERNS	2, 2, 2, 2, 5, 2, 2, 5, 5, 2, 2, 2, 2	13	MONITOR CLOUD PATTERNS	26
27	DETERMINE HUMIDITY OVER THE OCEAN	2, 2, 5, 5, 5, 5, 2, 2, 5, 2, 2, 2, 2	13	DETERMINE HUMIDITY OVER THE OCEAN	27
28	MONITOR LOW LEVEL ATMOSPHERIC TURBULENCE	2, 2, 2, 2, 2, 2, 2, 2, 2, 5, 2, 5, 5, 5, 5, 2, 2	17	MONITOR LOW LEVEL ATMOSPHERIC TURBULENCE	28
29	MONITOR HURRICANE AND TYPHOON FORMATIONS	2, 5, 2, 10, 2, 2, 10, 2, 5, 5, 5, 2, 2, 2, 5, 2, 5, 2	18	MONITOR HURRICANE AND TYPHOON FORMATIONS	29
30	TRACK STORM PATHS	2, 2, 2, 5, 2, 2, 5, 2, 2	9	TRACK STORM PATHS	30
31	DETERMINE ANOMALIES IN THE ELECTROMAGNETIC FIELD	2, 2, 10, 5, 2, 2, 10	7	DETERMINE ANOMALIES IN THE ELECTROMAGNETIC FIELD	31
32	DETERMINE ANOMALIES IN THE GRAVITY FIELD	2, 10, 10	3	DETERMINE ANOMALIES IN THE GRAVITY FIELD	32
33	LOCATE SLICKS	2, 2, 2, 2, 2	5	LOCATE SLICKS	33
34	DETERMINE TEMPERATURE DISTRIBUTION	5, 5, 5, 2, 2, 5, 2, 2, 2, 5, 5, 5, 2, 5, 2, 5, 5, 5, 5	19	DETERMINE TEMPERATURE DISTRIBUTION	34
35	DETERMINE MIXED LAYER DEPTHS	5, 2, 2, 2, 5, 2, 2, 2, 2	9	DETERMINE MIXED LAYER DEPTHS	35
36	DETERMINE AREAS OF EVAPORATION AND CONDENSATION	2, 2, 5, 2, 5, 5, 5, 2, 5, 2, 2, 5, 2	13	DETERMINE AREAS OF EVAPORATION AND CONDENSATION	36
37	DETECT AND MONITOR SEA ICE AND ICEBERGS	5, 2, 5, 5	4	DETECT AND MONITOR SEA ICE AND ICEBERGS	37
38	PREDICT FOG (HORIZONTAL VISIBILITY)	5, 5, 2, 2, 2, 2, 2	7	PREDICT FOG (HORIZONTAL VISIBILITY)	38
39	DETERMINE SHORELINE GEOMORPHOLOGY	2, 5, 5, 5, 10, 5, 10, 5, 5	9	DETERMINE SHORELINE GEOMORPHOLOGY	39
40	DETERMINE CHEMICAL COMPOSITION DISTRIBUTION	2, 10, 10, 2, 5, 5, 5, 5, 5, 10, 5, 2	12	DETERMINE CHEMICAL COMPOSITION DISTRIBUTION	40
41	DETERMINE SEWAGE & INDUSTRIAL WASTE COMPOSITION AND DISPERSION	2, 2, 5, 5, 2, 5, 5, 5, 5, 5, 5, 5	13	DETERMINE SEWAGE & INDUSTRIAL WASTE COMPOSITION AND DISPERSION	41
42	DETERMINE COMPOSITION OF BOTTOM SEDIMENTS	5, 2, 5, 2, 2, 2, 2, 2, 2, 2, 5, 10	12	DETERMINE COMPOSITION OF BOTTOM SEDIMENTS	42
43	DETERMINE NUTRIENT DISTRIBUTION	5, 5, 2, 2, 5, 5, 10, 10, 5, 5, 2	11	DETERMINE NUTRIENT DISTRIBUTION	43
44	IDENTIFY AND MONITOR SHIP OPERATION	2, 10, 5, 10, 5, 5, 10, 5	8	IDENTIFY AND MONITOR SHIP OPERATION	44
45	LOCATE OBJECTS ON OCEAN SURFACE	5, 5, 5, 10, 5, 2	6	LOCATE OBJECTS ON OCEAN SURFACE	45
46	LOCATE AND IDENTIFY OBJECTS BENEATH OCEAN SURFACE	2, 5, 5, 5, 10	5	LOCATE AND IDENTIFY OBJECTS BENEATH OCEAN SURFACE	46
47	DETERMINE AEROSOL PARTICLE DISTRIBUTION (ATMOSPHERE)	5, 10, 10, 2	4	DETERMINE AEROSOL PARTICLE DISTRIBUTION (ATMOSPHERE)	47
48	DETERMINE AREAS OF SMALL SCALE OCEAN TURBULENCE	5, 5, 2, 2, 2, 2, 2, 5, 5, 5, 5, 5	12	DETERMINE AREAS OF SMALL SCALE OCEAN TURBULENCE	48
49	DETERMINE INANIMATE PARTICLE DISTRIBUTION	2, 2, 2, 2, 2, 5, 5, 2, 5, 5, 5, 5, 2, 2, 2, 2, 5, 5, 5, 5, 5	21	DETERMINE INANIMATE PARTICLE DISTRIBUTION	49

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 4-2 (page 1 of 2)
MATRIX OF APPLICATION (METEOROLOGY)

CRITICAL ISSUES

ECONOMIC USES: CHEMICAL RESOURCES / ENERGY / COMMERCE AND INDUSTRY / TRANSPORTATION
SOCIAL AND CULTURAL USES: RECREATION / LIFE / EDUCATION / POLLUTION
NATIONAL AND INTERNATIONAL USES: MONITORING / SECURITY / DATA EXCHANGE / RESCUE AND RECOVERY
KNOWLEDGE OF STATE: CHEMICAL / BIOLOGICAL / PHYSICAL

RELATIVE SCALE OF APPLICABILITY
LEGEND:
10-HIGH 5- 2-LOW

NO.	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	2.1.1.1.1	2.1.1.1.2	2.1.1.1.3	2.1.1.2.1	2.1.1.2.2	2.1.1.3.1	2.1.1.3.2	2.1.1.3.3	2.1.1.3.4	2.1.1.4.1	2.1.2.1.1	2.1.2.1.2	2.1.2.2.4	2.1.2.3.1	2.1.2.3.3	2.1.2.4.1	2.1.2.4.2	2.1.2.4.3	2.1.2.4.4
51	DETERMINE TEMPERATURE FIELD	2	5		5	5	2	5			5	2	5			2		5		5
52	DETERMINE AIR MOTION (ADVECTION, ACCELERATION) FIELD	2	5	5	10		10	5			2		10		5	2	5	10	2	5
53	DETERMINE ATMOSPHERE COMPOSITION AND MASS (PRESSURE FIELD)	5	2	10			2		5		2					2		5	5	
54	DETERMINE WATER VAPOR DISTRIBUTION	5	2		5	5			2	2		2				2		5		2
55	DETERMINE OZONE DISTRIBUTION			2		5			2					2			2	5	10	
56	DETERMINE AEROSOL PARTICLES, SOURCES, TYPES AND EXTENT	5	5		2	2										2			5	
57	DETERMINE ENERGY EXCHANGE	5	5		10	10														2
58	DETERMINE MOMENTUM EXCHANGE	5	5		5		2													2
59	DETERMINE DIFFUSION PROPERTIES IN THE ATMOSPHERE		2		2		5	5	2							2	5	10	2	2
60	DETERMINE EVAPORATION/CONDENSATION DISTRIBUTION	10	10		10									2		2				2
61	DETERMINE RADIATIVE PROPERTIES OF THE ATMOSPHERIC LAYERS AND BOUNDARIES	2	2		2	10				2		2		5		2				5
62	DETERMINE HEAT SOURCES AND SINKS	5	5		5	10	2			2	2	2	5				2	5		5
63	DETERMINE SPECTRAL DISTRIBUTION OF SOLAR RADIATION					10				5		5								
64	DETERMINE GLOBAL HEAT BALANCE	2			2	10														
65	DETERMINE THE RADIO PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE									10		10				2				
66	DETERMINE ACOUSTIC PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE															2				
67	DETERMINE EXTENT AND TEMPERATURE GRADIENT OF STABLE LAYERS	5	10		5		5	5		10	5		5		5			10	10	10
68	DETERMINE EXTENT OF SMALL-SCALE TURBULENCE/UNDULANCE	2	2		2		5	5	2		5		5		2	2		5	2	2
69	DETERMINE CLOUD PATTERNS	10	10			10					2					2				
70	DETERMINE CLOUD TYPE, HEIGHT, THICKNESS, AND DENSITY	10	10		5	10				2	5	2	5		2	2		5	5	2
71	DETERMINE CLOUD MOTION AND LIFE	10	10		5						2		5			2		5	2	
72	DETERMINE CLOUD DROPLET AND ICE CRYSTAL SIZE DISTRIBUTION	10	10			5														
73	DETERMINE PRECIPITATION EXTENT, TYPE, AND INTENSITY	10	10		5		5	5	2		2							10	10	10
74	DETERMINE POLLUTION SOURCES AND EXTENT	2	2	5		5	10	10	5					5		2	10	10	10	10
75	LOCATE AND TRACK AIRBORNE OBJECTS										5		2							
76	LOCATE JET STREAMS	2	2								5				2					
77	LOCATE AREAS OF FOG, ICING, AND CAT		5			2					10		5		5	2				
78	LOCATE AND TRACK SEVERE LOCAL STORMS (THUNDERSTORMS, TORNADOS, DUST STORMS, ETC.)	5	2							5	5	5			5			5	2	
79	LOCATE AND MONITOR LOCAL CIRCULATIONS	2	2	2	2		2	5	2		2		5					5	5	2
80	LOCATE AND MONITOR HURRICANES	5	2		5															
81	LOCATE AND MONITOR FOREST FIRES				2												5	5		
82	DETERMINE ICE AND SNOW COVER	5			2	5					2									
83	DETERMINE SURFACE WATER AREA, EXTENT, AND STATE	10			2	10														
84	LOCATE AND TRACK SURFACE OBJECTS																			
85	DETERMINE GENERAL CIRCULATION CHANGES	2	2		5						2		2					5		
86	DETERMINE CLIMATE CHANGES															2			2	
87	DETERMINE LAND USE DISTRIBUTION PATTERNS AND SURFACE CHARACTERISTICS	2				5							2				2			
88	MONITOR VOLCANIC ACTIVITY	2															5	5		
89	MONITOR LAND EROSION/SEDIMENTATION	2				2											5			
90	MONITOR MAN-MADE AND NATURAL EXPLOSIONS				2	2				5		5					5			
91	DETERMINE ATMOSPHERIC CHARACTERISTICS OF OTHER PLANETS					2														
92	DETERMINE ELECTRIC FIELD									5	2			2		2				2
93	MONITOR UPPER ATMOSPHERE PHENOMENA			2						5		5			5	5				

NO.	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	2.1.3.1.1	2.1.3.1.2	2.1.3.2.1	2.1.3.2.2	2.1.3.3.1	2.1.3.3.3	2.1.3.3.4	2.1.3.3.5	2.1.3.4.1	2.1.3.4.2	2.2.1.1	2.2.1.2	2.2.2.1	2.2.2.2	2.2.2.3	2.2.3.1	2.2.3.2	2.2.3.3	2.2.3.4
51	DETERMINE TEMPERATURE FIELD	2	2				10							2			5	10		2
52	DETERMINE AIR MOTION (ADVECTION, ACCELERATION) FIELD	5				5	5							5	5	5	2	10		
53	DETERMINE ATMOSPHERE COMPOSITION AND MASS (PRESSURE FIELD)	5					5					10	10				2	2	5	5
54	DETERMINE WATER VAPOR DISTRIBUTION	5					5		2					5	5		5	10	5	5
55	DETERMINE OZONE DISTRIBUTION											10								5
56	DETERMINE AEROSOL PARTICLES, SOURCES, TYPES AND EXTENT	2	2				2									10	2		10	2
57	DETERMINE ENERGY EXCHANGE		2				5											5		10
58	DETERMINE MOMENTUM EXCHANGE						5											5		5
59	DETERMINE DIFFUSION PROPERTIES IN THE ATMOSPHERE													2					2	
60	DETERMINE EVAPORATION/CONDENSATION DISTRIBUTION		5				5											5	2	5
61	DETERMINE RADIATIVE PROPERTIES OF THE ATMOSPHERIC LAYERS AND BOUNDARIES	10							2	5	5	2					5	5	2	10
62	DETERMINE HEAT SOURCES AND SINKS						5		2								5	5		5
63	DETERMINE SPECTRAL DISTRIBUTION OF SOLAR RADIATION								5								5		2	
64	DETERMINE GLOBAL HEAT BALANCE						5											2		5
65	DETERMINE THE RADIO PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE								10								5			2
66	DETERMINE ACOUSTIC PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE																5			2
67	DETERMINE EXTENT AND TEMPERATURE GRADIENT OF STABLE LAYERS	5					5		10								5	5		2
68	DETERMINE EXTENT OF SMALL-SCALE TURBULENCE/UNDULANCE																5	2		2
69	DETERMINE CLOUD PATTERNS	5	5			5	10			2	2							5	2	5
70	DETERMINE CLOUD TYPE, HEIGHT, THICKNESS, AND DENSITY	5	5			5	10	5	2	5	5							5		5
71	DETERMINE CLOUD MOTION AND LIFE	5	5			5	10			2	2							5	2	5
72	DETERMINE CLOUD DROPLET AND ICE CRYSTAL SIZE DISTRIBUTION		10				2										2	2	2	5
73	DETERMINE PRECIPITATION EXTENT, TYPE, AND INTENSITY	5	10			5	5	10		2	2			5	5		2	5	5	2
74	DETERMINE POLLUTION SOURCES AND EXTENT	10						5								5			5	2
75	LOCATE AND TRACK AIRBORNE OBJECTS									10	5			2		2		2	5	
76	LOCATE JET STREAMS					5	5													5
77	LOCATE AREAS OF FOG, ICING, AND CAT		2			10	5			2	2							2	2	2
78	LOCATE AND TRACK SEVERE LOCAL STORMS (THUNDERSTORMS, TORNADOS, DUST STORMS, ETC.)	10	2			5	10	10	5	2	2							2	5	2
79	LOCATE AND MONITOR LOCAL CIRCULATIONS	2				2	2							2	2	2		2	2	2
80	LOCATE AND MONITOR HURRICANES		2				5	10										2		2
81	LOCATE AND MONITOR FOREST FIRES	5																	2	
82	DETERMINE ICE AND SNOW COVER						2				2						2			5
83	DETERMINE SURFACE WATER AREA, EXTENT, AND STATE		5														2	5	5	5
84	LOCATE AND TRACK SURFACE OBJECTS									10	10									
85	DETERMINE GENERAL CIRCULATION CHANGES	5	2			10	10							5	5	5		5		5
86	DETERMINE CLIMATE CHANGES		2																2	
87	DETERMINE LAND USE DISTRIBUTION PATTERNS AND SURFACE CHARACTERISTICS																2		2	
88	MONITOR VOLCANIC ACTIVITY	5										2						2	2	
89	MONITOR LAND EROSION/SEDIMENTATION	2						2											2	
90	MONITOR MAN-MADE AND NATURAL EXPLOSIONS	5							5			2						2	2	
91	DETERMINE ATMOSPHERIC CHARACTERISTICS OF OTHER PLANETS																	2		
92	DETERMINE ELECTRIC FIELD								5								10			
93	MONITOR UPPER ATMOSPHERE PHENOMENA								2			5	5				5			2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

12

Table 4-2 (page 2 of 2)
MATRIX OF APPLICATION (METEOROLOGY)

KNOWLEDGE OF CHANGE: TRANSFORMATIONS OF MOMENTUM / TRANSFORMATIONS OF HEAT / TRANSFORMATIONS OF MASS / TRANSFORMATIONS OF COMPOSITION / PREDICTION SHORT RANGE / PREDICTION EXTENDED RANGE / PREDICTION LONG RANGE / MOD.- LARGE SCALE BOUNDARY HEATING / MOD.- LARGE SCALE ATMOS. HEATING / MOD.- SMALL SCALE BOUNDARY HEATING / MOD.- SMALL SCALE ATMOS. HEATING

EFFECTS ON CLIMATE: MACRO SCALE / MESO SCALE / MICRO SCALE

EFFECTS ON RESOURCES: LAND / PLANTS / LIVESTOCK

EFFECTS ON LIFE AND PROPERTY: COMMERCIAL / CIVIL / TRANSPORTATION / HUMAN LIFE

NO	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	2.2.3.1.A.1	2.2.3.1.A.2	2.2.3.1.A.4	2.2.3.1.A.5	2.2.3.1.B.1	2.2.3.1.B.2	2.2.3.1.B.3	2.2.3.1.B.4	2.2.3.1.B.5	2.2.3.1.B.6	2.2.3.1.C.1	2.2.3.1.D.1	2.2.3.1.D.2	2.2.3.1.D.3	2.2.3.1.D.4	2.2.3.1.D.5	2.2.3.1.D.6	2.2.3.1.D.7	2.2.3.1.D.8	2.2.3.1.D.9	2.2.3.1.D.10	2.2.3.1.D.11	2.2.3.1.D.12	2.2.3.2.A.1	2.2.3.2.A.4	2.2.3.2.B.1	2.2.3.2.B.4	2.2.3.2.C.1	2.2.3.2.C.5	2.2.3.3.A.1	2.2.3.3.A.2	2.2.3.3.A.3	2.2.3.3.A.4	2.2.3.3.B.1	2.2.3.3.B.2
51	DETERMINE TEMPERATURE FIELD	10	10	10	10	10	10	10		10	10			10		5	10		10			10			10	10	10	10	10	10				5	5	5
52	DETERMINE AIR MOTION (ADVECTION, ACCELERATION) FIELD	10	5	10	10	10	10			10	10	10	10	5	10		5	10	10	10	10		10		10	10	10	10	10	10	5		5	5	5	
53	DETERMINE ATMOSPHERE COMPOSITION AND MASS (PRESSURE FIELD)		5									10													5	10	10	10	10	10	2					10
54	DETERMINE WATER VAPOR DISTRIBUTION							10	10	10			10	10		10	10				10	10			10	10	10	10	10	10		10	10		10	10
55	DETERMINE OZONE DISTRIBUTION							2	10									10	10						2		2		2							10
56	DETERMINE AEROSOL PARTICLES, SOURCES, TYPES, AND EXTENT							2	10							10	10			10	10	10	10	10	5		5	2	5	5	2			5		5
57	DETERMINE ENERGY EXCHANGE																								10		10		10			5	5	2	10	5
58	DETERMINE MOMENTUM EXCHANGE	5	2																						10		10		10		2					
59	DETERMINE DIFFUSION PROPERTIES IN THE ATMOSPHERE									5			5					5		5			5		2		2		2		2					
60	DETERMINE EVAPORATION/CONDENSATION DISTRIBUTION								5					10		10					5	10		10	5		5		5			5	10	10	10	
61	DETERMINE RADIATIVE PROPERTIES OF THE ATMOSPHERIC LAYERS AND BOUNDARIES							10	5																5	5	10	10	10	10	5	10	5			10
62	DETERMINE HEAT SOURCES AND SINKS							5										5							2		5		5			5			5	5
63	DETERMINE SPECTRAL DISTRIBUTION OF SOLAR RADIATION																	5	10						2		5		5			5				5
64	DETERMINE GLOBAL HEAT BALANCE																	5	5						2		5		5		2	5				10
65	DETERMINE THE RADIO PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE																																			
66	DETERMINE ACOUSTIC PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE																																			
67	DETERMINE EXTENT AND TEMPERATURE GRADIENT OF STABLE LAYERS																														2					
68	DETERMINE EXTENT OF SMALL-SCALE TURBULENCE/UNDULANCE												2												2		2		2		5					
69	DETERMINE CLOUD PATTERNS							10	10						10	10	10					10		10	10		10		10		2				5	10
70	DETERMINE CLOUD TYPE, HEIGHT, THICKNESS, AND DENSITY															5	5					5		5	5		5		5		5		5	5	5	5
71	DETERMINE CLOUD MOTION AND LIFE																5					5		5	5		10		10		5				5	2
72	DETERMINE CLOUD DROPLET AND ICE CRYSTAL SIZE DISTRIBUTION														10	10	10					5		5	5		5		5				5	10	5	
73	DETERMINE PRECIPITATION EXTENT, TYPE AND INTENSITY																5					10		10	2		5		5		5				10	
74	DETERMINE POLLUTION SOURCES AND EXTENT																														5					2
75	LOCATE AND TRACK AIRBORNE OBJECTS	2																																		
76	LOCATE JET STREAMS																								2		5		5							
77	LOCATE AREAS OF FOG, ICING, AND CAT																								5		2		2			5	2	10		5
78	LOCATE AND TRACK SEVERE LOCAL STORMS (THUNDERSTORMS, TORNADOS, DUST STORMS, ETC.)																								10		10		10						5	
79	LOCATE AND MONITOR LOCAL CIRCULATIONS	2											2												5		2				5					
80	LOCATE AND MONITOR HURRICANES																								5		5		5						2	2
81	LOCATE AND MONITOR FOREST FIRES																														2					
82	DETERMINE ICE AND SNOW COVER																								2		5		5		5	10	5			
83	DETERMINE SURFACE WATER AREA EXTENT AND STATE				5			2			10			10							10				10		10		10		2	10	10	2		
84	LOCATE AND TRACK SURFACE OBJECTS																																			
85	DETERMINE GENERAL CIRCULATION CHANGES	5											5												5		10		10			2	2			
86	DETERMINE CLIMATE CHANGES																								2		2		2		5	5				
87	DETERMINE LAND USE DISTRIBUTION PATTERNS AND SURFACE CHARACTERISTICS			5	10			2			10			10						10			10		5		5		5		10	5	5	2		
88	MONITOR VOLCANIC ACTIVITY																								2		2		2							
89	MONITOR LAND EROSION/SEDIMENTATION																			2			2		2		2		2		2		2			
90	MONITOR MAN-MADE AND NATURAL EXPLOSIONS																																			
91	DETERMINE ATMOSPHERIC CHARACTERISTICS OF OTHER PLANETS																																			
92	DETERMINE ELECTRIC FIELD														5	5															2					
93	MONITOR UPPER ATMOSPHERE PHENOMENA	2																2	5							2		2		2						5

NO	SELECTED KNOWLEDGE REQUIREMENTS (SKR)	2.2.3.3.B.3	2.2.3.3.B.4	2.2.3.4.A.1	2.2.3.4.A.2	2.2.3.4.A.3	2.2.3.4.A.4	2.2.3.4.B.1	2.2.3.4.B.2	2.2.3.4.B.3	2.2.3.4.B.4	2.3.1.1.1	2.3.1.1.2	2.3.1.1.3	2.3.1.2.1	2.3.1.2.2	2.3.1.2.3	2.3.1.3.1	2.3.1.3.2	2.3.1.3.3	2.3.2.1.1	2.3.2.1.2	2.3.2.2.1	2.3.2.2.2	2.3.2.3.1	2.3.2.3.2	2.3.3.1.1	2.3.3.1.2	2.3.3.2.1	2.3.3.2.2	2.3.3.3.1	2.3.3.3.2	2.3.3.3.3	2.3.3.4.1	2.3.3.4.2	NUMBER OF OCCURENCES
51	DETERMINE TEMPERATURE FIELD		5				5	5	5		5	5			5			10			2	2	5	5	5	5	5	5	5	5	5	5	5	2	5	65
52	DETERMINE AIR MOTION (ADVECTION, ACCELERATION) FIELD	5	5	5		5	5	5		5	5	2			2			5				5	5	5	5	5	5	2	5		2	5	5	2	10	74
53	DETERMINE ATMOSPHERE COMPOSITION AND MASS (PRESSURE FIELD)			2						10				5			5			5									2	2		5	2	2		37
54	DETERMINE WATER VAPOR DISTRIBUTION				10	10		10	10			5			10			10			2	2	5		5		5	2	5	5	2	2				55
55	DETERMINE OZONE DISTRIBUTION								10			2	5		2	5	5																			23
56	DETERMINE AEROSOL PARTICLES, SOURCES, TYPES, AND EXTENT	10	5	2			5		5	10	5	2			2			2					2		2			2	2	2				5	2	47
57	DETERMINE ENERGY EXCHANGE		2		5	5	2	10	5		2	5	5		5	5																		2		29
58	DETERMINE MOMENTUM EXCHANGE			2										2			2			2																18
59	DETERMINE DIFFUSION PROPERTIES IN THE ATMOSPHERE	5		2						5				2			2			2								2						2		29
60	DETERMINE EVAPORATION/CONDENSATION DISTRIBUTION		10		5	10	10	10			10	2			5			5			2		2	2	2	2	2	2	5	2	2					43
61	DETERMINE RADIATIVE PROPERTIES OF THE ATMOSPHERIC LAYERS AND BOUNDARIES			5	10	5				10		10			10			10			5	5	10	5	10	5	2	5	5	5		2	5	5		50
62	DETERMINE HEAT SOURCES AND SINKS				5			5	5			10			10			10																		31
63	DETERMINE SPECTRAL DISTRIBUTION OF SOLAR RADIATION				5				5			10			10			10					5	5	5	5			2						5	24
64	DETERMINE GLOBAL HEAT BALANCE			2	5				10			10			10			10																		20
65	DETERMINE THE RADIO PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE																										5		2			2	2		5	11
66	DETERMINE ACOUSTIC PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE																																			3
67	DETERMINE EXTENT AND TEMPERATURE GRADIENT OF STABLE LAYERS			2										5			5			5							2			5			2	2	5	28
68	DETERMINE EXTENT OF SMALL-SCALE TURBULENCE/UNDULANCE			5																							5					5	5		2	26
69	DETERMINE CLOUD PATTERNS			2			2	5	10			10			10			10									5		2	5		5	5			39
70	DETERMINE CLOUD TYPE, HEIGHT, THICKNESS, AND DENSITY		5	5		5	5	5	5		5	2			5			5					5		5		5	5	5	5		5	5		2	54
71	DETERMINE CLOUD MOTION AND LIFE			5				5	2									2									5	2				5				33
72	DETERMINE CLOUD DROPLET AND ICE CRYSTAL SIZE DISTRIBUTION		10			5	10	5			10			2			2			2												2				29
73	DETERMINE PRECIPITATION EXTENT, TYPE AND INTENSITY	5	10	5				10		5	10	2			5			5			5	10	10	10	10	10	10	5	10	10	10	2	5	5	10	55
74	DETERMINE POLLUTION SOURCES AND EXTENT	5		5					2	5		2	2		2	2		5						5		5		5	5	5				5		35
75	LOCATE AND TRACK AIRBORNE OBJECTS																				2	5	5	5	5	5	2		2	2		2			5	20
76	LOCATE JET STREAMS																										5					10	5			13
77	LOCATE AREAS OF FOG, ICING, AND CAT		10		5	2	10		5		10																		2	2	10	10	5		2	33
78	LOCATE AND TRACK SEVERE LOCAL STORMS (THUNDERSTORMS, TORNADOS, DUST STORMS, ETC.)	5						5		5												2	2	5	2	5	5	2	5	2	5	10	5		2	39
79	LOCATE AND MONITOR LOCAL CIRCULATIONS	2		5	5	5				2						5						2	2	2	2	2	2	5	2	5					10	42
80	LOCATE AND MONITOR HURRICANES							2	2			2			2			2				2	2	5	2	5	2	2	2	5	5		5			29
81	LOCATE AND MONITOR FOREST FIRES			10																		10		10		10		5	5	5					10	14
82	DETERMINE ICE AND SNOW COVER			5	10	5						5			10			10				5	5	5	5	5	5	5	5	5	10					30
83	DETERMINE SURFACE WATER AREA EXTENT AND STATE		2	2	10	10	2				2	5			10			10				5	2	5	2	5	5	5	5	5						38
84	LOCATE AND TRACK SURFACE OBJECTS																																			2
85	DETERMINE GENERAL CIRCULATION CHANGES												10			10											5	2	5	10		5	5		5	31
86	DETERMINE CLIMATE CHANGES	2		5	5	5				2		10	10	10	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	10						33
87	DETERMINE LAND USE DISTRIBUTION PATTERNS AND SURFACE CHARACTERISTICS	2	2	2	5	5	2			2	2	5			5			5	10		5	5	5	5	5	5			2	5						39
88	MONITOR VOLCANIC ACTIVITY	5								5																				5				10		14
89	MONITOR LAND EROSION/SEDIMENTATION	2		2						2		2			2			2	5			5		5		5			5	5						24
90	MONITOR MAN-MADE AND NATURAL EXPLOSIONS																																			11
91	DETERMINE ATMOSPHERIC CHARACTERISTICS OF OTHER PLANETS																																			2
92	DETERMINE ELECTRIC FIELD		5				5				5									5		5		5		2	2	2	5		2	5	2		5	24
93	MONITOR UPPER ATMOSPHERE PHENOMENA								5			2			2	2	2						2	2	2	2										26

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 4-3
SELECTED KNOWLEDGE REQUIREMENTS (Oceanography)

	MEASUREMENT REQUIREMENTS	01 DETERMINE FISH POPULATION DISTRIBUTION	02 DETERMINE OCEAN BIOTA (POPULATION DYNAMICS)	03 DETERMINE AREAS OF USEFUL TIDAL ACTION	04 DETERMINE OCEAN CURRENT DISTRIBUTION	05 DETERMINE OCEAN SURFACE ROUGHNESS (SEA STATE)	06 PREDICT WAVE CHARACTERISTICS	07 DETERMINE NEAR SURFACE WIND DISTRIBUTION	08 PREDICT SEA SURFACE WINDS	09 DETERMINE AREAS OF UPWELLING	10 DETERMINE ENERGY EXCHANGE ACROSS THE AIR/SEA INTERFACE	11 DETERMINE MOMENTUM FLUX AT THE AIR/SEA INTERFACE	12 DETERMINE AREAS OF CONVERGENCE OR DIVERGENCE	13 DETERMINE CHANGES IN MEAN SEA HEIGHT	14 MONITOR LAND EROSION/ACCRETION AT THE LAND/SEA INTERFACE	15 DETERMINE AREAS OF POTENTIAL TURBIDITY CURRENTS	16 DETERMINE BREAKER AND SURF CHARACTERISTICS	17 DETECT AND MONITOR TSUNAMIS	18 DETERMINE INTERNAL WAVE CHARACTERISTICS	19 DETERMINE BOTTOM TOPOGRAPHY	20 LOCATE OIL AND MINERALS	21 DETERMINE DISTRIBUTION OF OCEAN SURFACE CHANGE	22 DETERMINE WATER COLUMN STABILITY	23 DETERMINE SUBMARINE VOLCANO ACTIVITY	24 DETERMINE HEAT FLOW ACROSS THE AIR/SEA INTERFACE	25 DETERMINE LOWER ATMOSPHERE STABILITY	26 MONITOR CLOUD PATTERNS	27 DETERMINE HUMIDITY OVER THE OCEAN	28 MONITOR LOW LEVEL ATMOSPHERIC TURBULENCE	29 MONITOR HURRICANE AND TYPHOON FORMATIONS	30 TRACK STORM PATHS	31 DETERMINE ANOMALIES IN THE ELECTROMAGNETIC FIELD	32 DETERMINE ANOMALIES IN THE GRAVITY FIELD	33 LOCATE SLICKS	34 DETERMINE TEMPERATURE DISTRIBUTION	35 DETERMINE MIXED LAYER DEPTH	36 DETERMINE AREAS OF EVAPORATION AND CONDENSATION	37 DETECT AND MONITOR SEA ICE AND ICEBERGS	38 PREDICT FOG (HORIZONTAL VISIBILITY)	39 DETERMINE SHORELINE GEOMORPHOLOGY	40 DETERMINE CHEMICAL COMPOSITION DISTRIBUTION	41 DETERMINE SEWAGE AND INDUSTRIAL WASTE COMPOSITION AND DISPERSION	42 DETERMINE COMPOSITION OF BOTTOM SEDIMENTS	43 DETERMINE NUTRIENT DISTRIBUTION	44 IDENTIFY AND MONITOR SHIP OPERATIONS	45 LOCATE OBJECTS ON OCEAN SURFACE	46 LOCATE AND IDENTIFY OBJECTS BENEATH OCEAN SURFACE	47 DETERMINE AEROSOL PARTICLE DISTRIBUTION	48 DETERMINE AREAS OF SMALL SCALE OCEAN TURBULENCE	49 DETERMINE INANIMATE PARTICLE DISTRIBUTION	NUMBER OF OCCURRENCES
001	SEA COLOR	5	5		2	2				5			2				5			5	2			2										5				5		5	2	2	2	5						5	18
002	TURBIDITY	2	5		2					2	2		2		2								2																		2	5		5					2	2	13
003	BIOLUMINESCENCE	5	5							2																								2								2		5	2						7
004	CLOUD PATTERNS	2	2					5	5	5	2	2	5												5	5	10		5	5	5				2		2		5												17
005	COASTLINE PATTERNS			5						5		2	5		10	5	5	5		2	5			2								2	5							10		5									15
006	STORM TRACKING			2	2	2	5		5	5	2	2	5		2	5	5		2							5	5		5	5	10	2			2		2		5												22
007	SEA SURFACE TEMPERATURE	10	5		5				2	10	5		5						5					5	5	5	5	5	5	5				5	10		2	5	5					2	2		5				23
008	SEA TEMPERATURE VERTICAL PROFILE	5	5		5					2	5	2		5					5				10		10										5	5					2	2		5			5		5	2	18
009	HEAT FLOW										10												2	5	10	5	5		5	5				2	2		5	5													12
010	ATMOSPHERIC VERTICAL TEMPERATURE PROFILE (LOW-LEVEL)					2	2		2		5	2													10	10	5	2	5	5					2		5		5												14
011	ATMOSPHERIC MOISTURE PROFILE (LOW-LEVEL)										5														5	5	5	10	5	5					2		5		5									5			10
012	ATMOSPHERE COLOR										2													2		5	5																					5			5
013	SURF PATTERNS			5		2									5	2	10			2	2																			5								2	2		10
014	PRECIPITATION PATTERNS										5														2		5	5									5		5												6
015	WAVE HEIGHT					10	5		2		5	5					2		2				2							2	2																				11
016	WAVE PERIOD					10	5	5	2		5	5					2		2				2							2	2																				11
017	WAVE DIRECTION					5	5	5	2		2	5					2		2				2							2	2																				11
018	SURFACE WIND			2	5	5	10	10	10		5	5	5				2		2							2	5	5	2	10	10					5	2		5									5	5		22
019	VERTICAL WIND PROFILE				2	2	5	5	5		5	10	2									2			5	5	2	5	10	2							5		5												16
020	CHANGE IN MEAN SEA HEIGHT			5	5								5	10				10	5											2	2																				8
021	WAVE PATTERNS					5	5	5	5		2	2	2		2		5									2			2	5	5											5			5		2		2		18
022	GLITTER PATTERNS					5		5	2			2																	2					5				2													7
023	SLICK PATTERNS	2	5					5	2	5	2	2	5						5		5				2									10	2							5		5	5		2				17
024	DEPTH PROFILE			5											2	10	2	5		10	5			5								2	5							5		5									12
025	LOCATE AND TRACK SURFACE/SUBSURFACE OBJECTS	2																																				10							10	10	10				5
026	SALINITY	2	2							2				2																											5	2		5						2	8
027	ACOUSTIC SIGNATURE	5				2																							2																5				2		5
028	MIXED LAYER DEPTH	5	2			2				2		2	2										5													10													2		9
029	MEASURE CURRENT				10	2					5	5	5	5	5	2		5	5																5							5		2					5		14
030	BAROMETRIC PRESSURE			2	2			5	5					2													2			5	10																				8
031	SPECTRAL ANALYSIS (ABSORPTION/EMISSION SIGNATURES)	2	5																																						5	5	2					5		5	7
032	GRAVITATIONAL ANOMALIES																			2	5			2								2	10							2			2		5						8
033	MAGNETIC ANOMALIES																				5	2								2	2	10	2										2		5		5				9
034	BOTTOM COMPOSITION															5				2				5								2	5								2		10	2			5			2	10
035	SURFACE CHARGE				2						2											10		2			2	2		2		2		2			2		2	2							2	5			14

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Table 4-4
SELECTED KNOWLEDGE REQUIREMENTS (Meteorology)

	MEASUREMENT REQUIREMENTS	51 DETERMINE TEMPERATURE FIELD	52 DETERMINE AIR MOTION FIELD (ADVECTION, ACCELERATION)	53 DETERMINE ATMOSPHERE COMPOSITION AND MASS (PRESSURE FIELD)	54 DETERMINE WATER VAPOR DISTRIBUTION	55 DETERMINE OZONE DISTRIBUTION	56 DETERMINE AEROSOL PARTICLES, SOURCES, TYPES, AND EXTENT	57 DETERMINE ENERGY EXCHANGE	58 DETERMINE MOMENTUM EXCHANGE	59 DETERMINE DIFFUSION PROPERTIES IN THE ATMOSPHERE	60 DETERMINE EVAPORATION/CONDENSATION DISTRIBUTION	61 DETERMINE RADIATIVE PROPERTIES OF THE ATMOSPHERIC LAYERS & BOUNDARIES	62 DETERMINE HEAT SOURCES & SINKS	63 DETERMINE SPECTRAL DISTRIBUTION OF SOLAR RADIATION	64 DETERMINE GLOBAL HEAT BALANCE	65 DETERMINE THE RADIO PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE	66 DETERMINE ACOUSTIC PROPAGATION CHARACTERISTICS OF THE ATMOSPHERE	67 DETERMINE EXTENT AND TEMPERATURE GRADIENT OF STABLE LAYERS	68 DETERMINE EXTENT OF SMALL SCALE TURBULENCE/UNDULANCE	69 DETERMINE CLOUD PATTERNS	70 DETERMINE CLOUD TYPE, HEIGHT, THICKNESS, AND DENSITY	71 DETERMINE CLOUD MOTION AND LIFE	72 DETERMINE CLOUD DROPLET AND ICE CRYSTAL SIZE DISTRIBUTION
051	PRESSURE	5	5	10		2	5	5	5				2		5			2		2		2	
052	TEMPERATURE	10			2			2			5	10	2	5	5	2	2	5		2	5	2	
053	EMISSIVITY	10				5							5		5	2				10	10		5
054	WATER VAPOR	10		5	10		5	5		2	10	5		2	5	5				10	5	5	10
055	GAS CONCENTRATION (CO_2, O_3, NO ETC.)	5		10		10		5		2		5	5	5	5		5	2					
056	ATOMIC & MOLECULAR CONCENTRATION & EFFECTS			10				5				2		5		5							
057	LIQUID SIZE, SHAPE, & CONCENTRATION			5	5		2				10	5		2	2	2			2	10	10	10	10
058	ICE SIZE, SHAPE, & CONCENTRATION	5		5								2		5	2					5	10	5	10
059	AEROSOL SIZE, SHAPE, & CONCENTRATION	2		2			10				5			2				5					
060	ELECTRIC CHARGE				2		2				2									5			2
061	ELECTRIC DISCHARGE																			5			
062	IONIZATION			2		5		2						5		2							
063	MAGNETIC ANOMALY													5		2							
064	AIR & CLOUD HORIZONTAL MOTION	5	10	5		5	5	2	2	5	5						2			2		10	
065	AIR & CLOULD VERTICAL MOTION	5	10	5		2		2	5	2	5									5	5	5	
066	COLOR			2								5											
067	AIRBORNE OBJECTS - SIZE, SHAPE, AND CONCENTRATION	5	10	5	5	2	2	2	2	5	2	2	2	2				2	2	2	2	5	
068	DENSITY	5	5	10	5	2											2			2	2		
069	REFLECTION	2	5								5	10	2	5	5					10	10	5	5
070	HEAT FLUX	5			5	2		5			5	10	10	5	5					5			
071	ACOUSTIC SIGNATURE	2			2												10	5	5	2	2		
072	SCATTERING	2	2	5	5	5	10	2	2	5	2	10	2	5	2	2	2	2		5	2		5
073	RADAR & MICROWAVE SIGNATURES	5	5								5	5							2	5	5	5	2
074	CLOUD PATTERNS	10	5	2	5						10	10	10	5	10		2	2	2	10	5	5	5
075	CLOUD HEIGHT	2	2		5			5			10	5	10	5	5		2	2	2		10	5	5
076	SUN GLINT		10																	5	2		
077	SURFACE ROUGHNESS	2	5	2	5		5	5	5		2				2			2	5	2	2	2	
078	TURBULENCE	5	5					2	2				2					5	5				
079	PRECIPITATION				2			2			10		2		2					5	10	5	10

	MEASUREMENT REQUIREMENTS	73 DETERMINE PRECIPITATION EXTENT, TYPE, AND INTENSITY	74 DETERMINE POLLUTION SOURCES AND EXTENT	75 LOCATE AND TRACK AIRBORNE OBJECTS	76 LOCATE JET STREAMS	77 LOCATE AREAS OF FOG, ICING, AND CAT	78 LOCATE & TRACK SEVERE LOCAL STORMS (THUNDERSTORMS, TORNADOS, DUST, ETC.)	79 LOCATE AND MONITOR LOCAL CIRCULATION	80 LOCATE AND MONITOR HURRICANES	81 LOCATE AND MONITOR FOREST FIRES	82 DETERMINE ICE AND SNOW COVER	83 DETERMINE SURFACE WATER AREAL EXTENT AND STATE	84 LOCATE AND TRACK SURFACE OBJECTS	85 DETERMINE GENERAL CIRCULATION CHANGES	86 DETERMINE CLIMATE CHANGES	87 DETERMINE LAND USE DISTRIBUTION PATTERNS AND SURFACE CHARACTERISTICS	88 MONITOR VOLCANIC ACTIVITY	89 MONITOR LAND EROSION/SEDIMENTATION	90 MONITOR MAN MADE AND NATURAL EXPLOSIONS	91 DETERMINE ATMOSPHERIC CHARACTERISTICS OF OTHER PLANETS	92 DETERMINE ELECTRIC FIELD	93 MONITOR UPPER ATMOSPHERE PHENOMENA	OCCURRENCE
051	PRESSURE	2			2		2		2					5		2	2		2	2			21
052	TEMPERATURE	5			2	2				2	5								2	2	2		22
053	EMISSIVITY	10	2	2	2	10	10	2								5							16
054	WATER VAPOR	10				5	2				2	2			2					2	2		23
055	GAS CONCENTRATION (CO_2, O_3, NO ETC.)		5	2						2					2		2						16
056	ATOMIC & MOLECULAR CONCENTRATION & EFFECTS													2					2	5	2	10	10
057	LIQUID SIZE, SHAPE, & CONCENTRATION	10				5														5			16
058	ICE SIZE, SHAPE, & CONCENTRATION	10	2								10	5								5			14
059	AEROSOL SIZE, SHAPE, & CONCENTRATION	5	10							5							5			2			11
060	ELECTRIC CHARGE	5							2								2				10	2	10
061	ELECTRIC DISCHARGE	5	2				5		2							2	2				10	2	9
062	IONIZATION		2																2	5	5	5	10
063	MAGNETIC ANOMALY						2		2												10		5
064	AIR & CLOUD HORIZONTAL MOTION	5		5	2	2	5	5	2	2				5	2	2	2					2	25
065	AIR & CLOULD VERTICAL MOTION	10		5	2	2	5	5	2	2						2	2		2			2	23
066	COLOR		5			2				5	2	5				10	5	10		5			11
067	AIRBORNE OBJECTS - SIZE, SHAPE, AND CONCENTRATION		5	10	2			2						5							2	2	25
068	DENSITY			2				2						5						2			12
069	REFLECTION	5			2	10			5		10	10			5	10		2					20
070	HEAT FLUX	5					2			5	2	5		2		2	5			5		2	20
071	ACOUSTIC SIGNATURE																		5	2		2	10
072	SCATTERING		5			2	2						2	2		5	5	2	2	5		2	31
073	RADAR & MICROWAVE SIGNATURES	10		5	2		10		10		10	5	5			5	2	2		5			21
074	CLOUD PATTERNS	2			5	5	5		10					5	2				5	5	2	5	27
075	CLOUD HEIGHT	5			2	2	5	2	10											2			22
076	SUN GLINT					2						10											5
077	SURFACE ROUGHNESS	5	2			2		5			5	5			2	10							22
078	TURBULENCE	5			5	10	5		2	2						2			5				16
079	PRECIPITATION	10	2		2	2	2		2						2								16

FOLDOUT FRAME 1

FOLDOUT FRAME 2

Section 5

STUDY RESULTS

The ORDS, when taken as a composite set of potential measurements for orbital oceanography and meteorology, provided interesting insights into the general observational patterns which might be anticipated in future research programs. The patterns or trends observed suggest answers to mission-planning questions regarding the spectral regions of importance, the grid-point sampling intervals, the frequency with which the measurements should be made, the role of potential observational platforms, the role of man, orbital operation requirements, and the specific instruments or sensors needed for a comprehensive measurement program.

5.1 SPECTRAL REGIONS OF INTEREST

For a comprehensive measurement program in orbital oceanography and meteorology, the principal spectral regions of interest are the visible (0.4 to 0.8μ), infrared (0.8 to 50μ), and microwave (10^3 to 10^5μ) bands. Spectral-sensing requirements for 31 of the more important measurement areas are summarized in Figures 5-1 and 5-2. For nearly every phenomenon of interest, measurements were required in more than one spectral region. In many cases, multiband sensing was required to provide secondary or "control" data which could be used to aid in interpreting the significance of the data gathered in the spectral region of primary measurement interest. As an example, IR upwelling from the Earth's surface in the 10 to 11μ region is occulted or attenuated by clouds in the field of view. Since the energy detected would be radiated at the cloud's temperature, a control measurement is needed (probably in the visible region) to verify the radiation source.

Because of their three-dimensional nature, meteorological phenomena generally require a greater number of wavelength regions in their measurement programs than do oceanographic phenomena. To illustrate, the differential absorption bands of the various constituents of the Earth's atmosphere are important factors in controlling the amount of the reflected and scattered radiation which could be observed from the vantage point of space. Comparison of the relative amounts of reflected and scattered radiation in various portions of the electromagnetic spectrum provides a feasible technique for assessing such factors as cloud cover; cloud heights; precipitation; surface temperature; and the vertical distribution of temperature, water vapor, CO_2, and ozone. Since the oceanographic measurements feasible from remote platforms are essentially of a two-dimensional nature, it appears that less need exists for broadband coverage. Required oceanographic measurements were found

	ULTRA-VIOLET	VISIBLE 0.4 TO 0.8	NEAR IR 0.8 TO 3μ	MIDDLE IR 3.0 TO 50μ	FAR IR 50 TO 10^3μ	MICROWAVE 10^3 TO 10^5μ
PLANKTON AND FISH		○				○
SURFACE OBJECTS		○				○
CLOUD PATTERNS		○	○	○		●
LOCAL WINDS		○				●
SLICKS	○	●		○		
SEA STATE		○				○
WAVES		●				○
SURF		○				○
SEA SURFACE TEMP.		●		○		●
ICEBERGS		●		○		●
OCEAN CURRENTS		●	○	○		○
POLLUTION		○●	○	○	○	●
COASTAL FEATURES		○				●
ANOMALIES						
BOTTOM COMPOSITION		○				
AIR-SEA INTERFACE		○	○	○		○

LEGEND ○ PRIMARY ● CONTROL

Figure 5-1. Space Sensing Spectral Requirements-Oceanography

	ULTRA-VIOLET	VISIBLE 0.4 TO 0.8μ	NEAR IR 0.8 TO 3μ	MIDDLE IR 3 TO 50μ	FAR IR 50 TO 10^3μ	MICROWAVE 10^3 TO 10^5μ
SURFACE TEMPERATURE		●		○		○
VERTICAL TEMP. PROFILE		●		○		○
SURFACE WINDS		○				○
VERTICAL WINDS PROFILE		●		○		○
SURFACE MOISTURE		●		○		○
VERT. WATER VAPOR PROFILE		●		○		○
CLOUD COVER		○●	○	○		
CLOUD TOP HEIGHT		○●	○	○		
PRESSURE		○	○			○
SEVERE STORMS		○●	○	○		○
PRECIPITATION						○
HEAT BUDGET	○	○●	○	○	○	○
AIR POLLUTION		○●	○	○		○
CLEAR AIR TURBULENCE		●		○		○
SNOW, ICE COVER		○●	○	○		○

Figure 5-2. Space Sensing Spectral Requirements-Meteorology

to lie primarily in just two regions, the visible and microwave. Color photography would provide directly usable data on the dynamics of ocean waters, plankton content, ice coverage, cloud coverage, sea state, and many other phenomena. Microwave measurements of surface temperature gradients are preferred over the IR, since they are not appreciably affected by clouds or atmospheric water vapor. Considerable research and ground truth testing is required, however, before the feasibility of microwave systems can be established.

5.2 SPATIAL RESOLUTION (GRID-POINT SAMPLING)

For each of the items identified in the study, the required distance between discrete measurements (grid-point sampling) was determined. This spatial resolution should not be confused with the resolution of the parameter in terms of accuracy and precision of the measurement. Rather, it is the sampling distance or spatial variability of the phenomena of interest. A comparison of the data plotted in Figures 5-3 and 5-4 suggests that oceanographic phenomena require measurements made at closer spatial intervals than meteorological phenomena.

5.3 TEMPORAL RESOLUTION (SAMPLING FREQUENCY)

Observation or data-sampling frequency (Figures 5-5 and 5-6), i.e., the interval of elapsed time subsequent measurements of each parameter at the same grid point, was also examined. Measurement of meteorological parameters required sampling at more frequent time intervals than oceanographic parameters. In Figures 5-5 and 5-6, a horizontal line delineates the range of observation frequencies required for each parameter. The horizontal lines reflect the range of sampling rates from "desired" through "usable." It should be noted that the span of observation-frequency requirements for plankton and fish varies from hourly to monthly data. The extended range associated with biological parameters results from the study of marine life and its ecology, in which life cycles which vary from hours to decades are observed.

5.4 OBSERVATIONAL PLATFORMS

The information contained in Figures 5-3, 5-4, 5-5, and 5-6 are cross plotted in Figure 5-7. While similar regions of the spectrum are of interest to oceanographers and meteorologists (Figures 5-1 and 5-2), the observation programs are quite different. The oceanographic events change more slowly than meteorological phenomena but require finer grid-point sampling intervals. Requirements for synoptic and continued coverage of

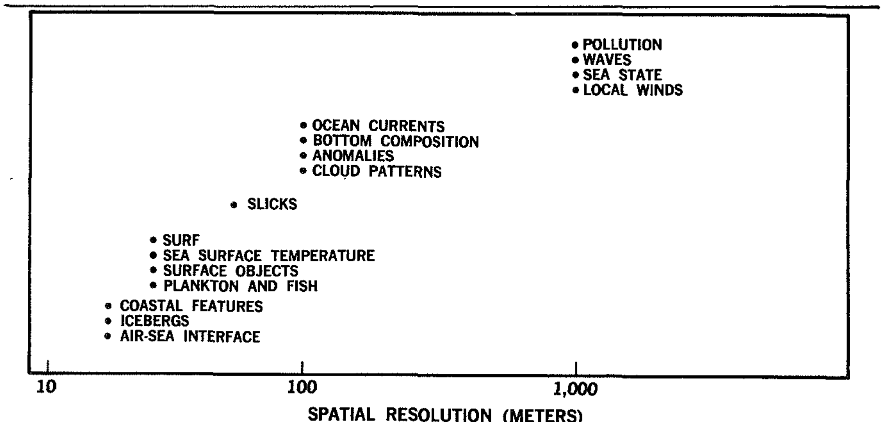

Figure 5-3. Spatial Resolution Requirements-Oceanography

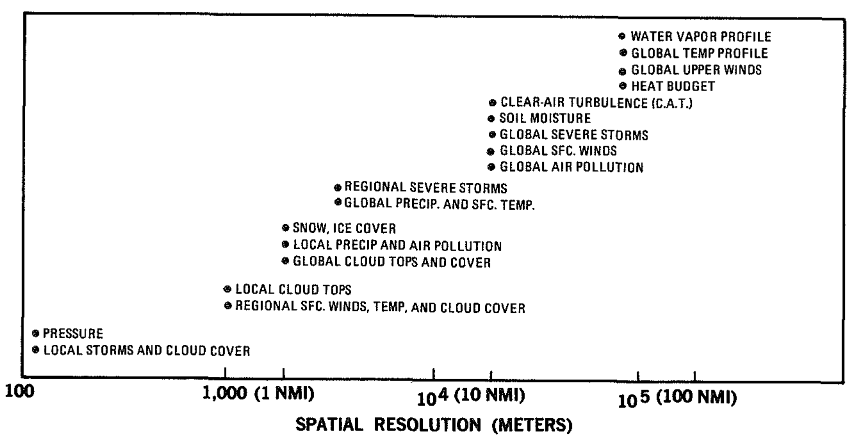

Figure 5-4. Spatial Resolution Requirements-Meteorology

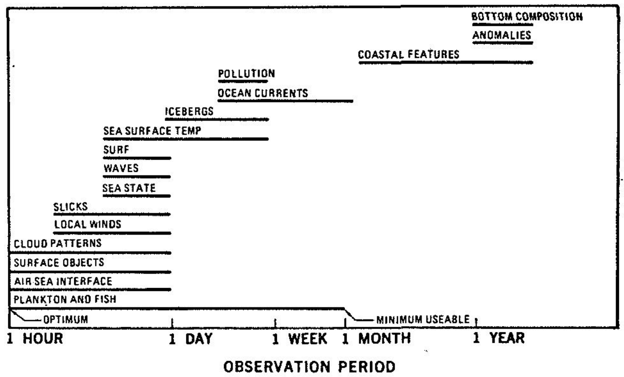

Figure 5-5. Observation Frequency Requirements-Oceanography

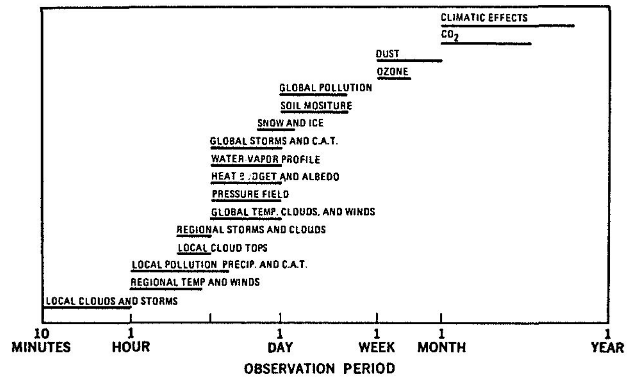

Figure 5-6. Observation Frequency Requirements-Meteorology

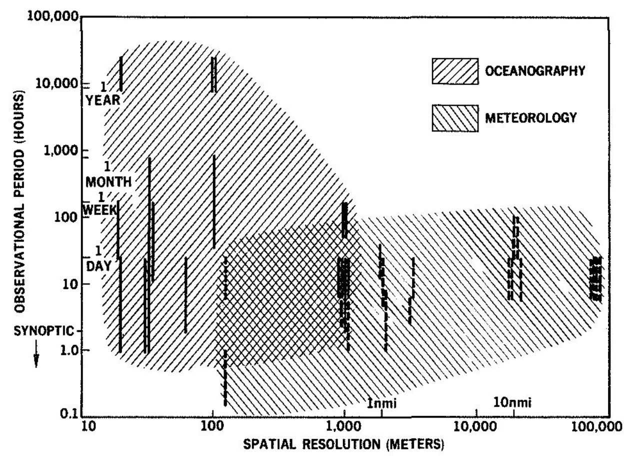

Figure 5-7. O&M Data Requirements Summary-A

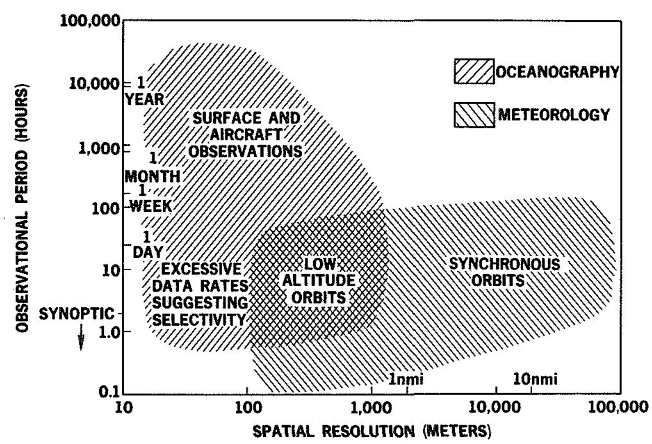

Figure 5-8. O&M Data Requirements Summary-B

meteorological events require data gathering on an hourly to daily basis as contrasted to oceanographic measurements which require daily to yearly sampling intervals.

These observational patterns suggest that different orbital platforms may be required (Figure 5-8). The relatively coarse measurements requiring frequent observations, typical of certain global weather events, would be adequately accommodated by vehicles in synchronous orbits. The very slowly changing oceanographic phenomena requiring relatively fine spatial resolution would be adequately accommodated by surface and aircraft observations. The oceanographic and meteorological measurements made frequently with fine spatial resolution might be obtained by satellite in low-altitude orbits.

The program defined included two major measurement elements: an R&D phase and an operational phase (Figure 5-9). The development of instruments, measurement techniques, and operational theories or models are the R&D objectives. The operational systems involve the more routine data gathering, processing, and dissemination. As descriptive and predictive techniques are developed in the R&D phase, they in turn establish the sensors, data processors, and information interfaces needed in the operational system by the using agencies.

The shifting pattern of demands for measurement platforms was examined for the R&D (Figure 5-10) and the operational phases (Figure 5-11). Orbital facilities, aircraft, surface vehicles, and multiple combinations, including orbital platforms, were considered. Criteria used in identifying the most responsive type of measurement platform were (1) projected equipment development status and space flight worthiness of instruments; (2) necessity for concurrent measurements, such as ground-truth verification; (3) the required geographical coverage and resolution; and (4) the periodicity, frequency, and duration of the observations.

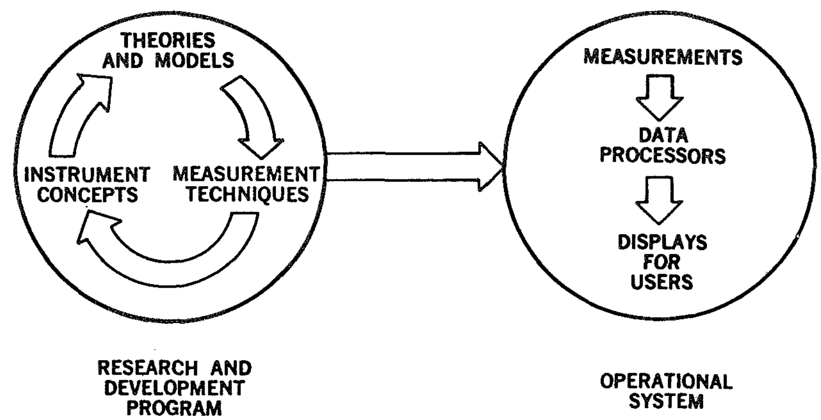

Figure 5-9. Technical Objective Achievement

Most orbital measurements identified for the R&D phase required ancillary verification or "ground truth" testing. Certain theoretical studies, however, could be verified by specific experiments performed on the orbital platform. These generally relied on some unique advantages of orbital space (zero-g, synoptic coverage capability, etc.). An example is the zero-g required in various experiments dealing with cloud physics and weather modification mechanisms.

Some measurements were identified by the scientific contributors as being of potentially great value if they could be made on a synoptic basis, even though no feasible technique was currently available for remote sensing. These types of measurements were included in the analysis for completeness but were identified as being feasible only from surface vessels. Examples are sea-surface electric charge and gravitational and magnetic anomalies.

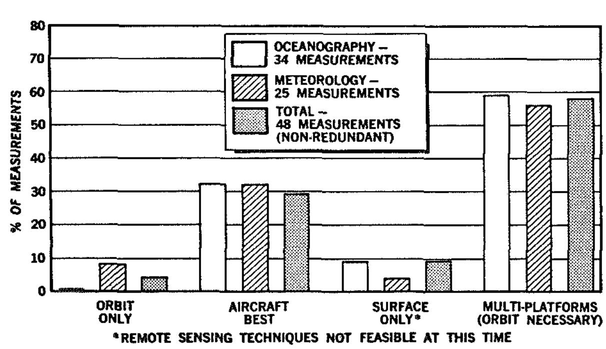

Figure 5-10. Measurement Platforms-Research and Development Phase

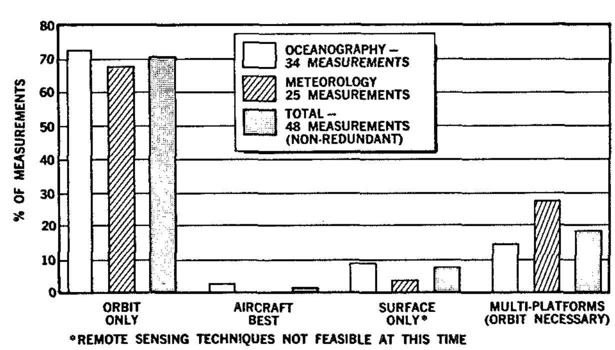

Figure 5-11. Measurement Platforms-Research and Operational Phase

As the emphasis on the measurement programs shifts towards the operational systems, the use of independent orbital facilities becomes more important (Figure 5-11). However, aircraft appear to continue to offer advantages in those operational areas dealing with the assessment of such slowly changing phenomena as coastline patterns and bottom anomalies. These trends are based solely on the expected ability of the given platform to satisfactorily accomplish the observations. The comparative operating economies of the various platforms were not considered in this study.

5.5 THE ROLE OF MAN

Although an evaluation of the role of man in orbital operations involves analysis beyond the scope of the present study, the data at hand permitted at least a preliminary assessment of his potential contribution. The rationale followed in this analysis acknowledged that man could be "engineered" out of the orbital system but usually at the price of increased complexity, decreased reliability, and decreased system capability. On the other hand, man requires complex support equipment and is therefore costly. Each measurement requirement was analyzed to determine the nature of man's possible contributions to the program and how they might change the R&D and the operational phase. Five potential contributions of man were identified:

1. Selection of targets.
2. Checking of complex instrument functioning.
3. Calibration and testing of new and complex instruments.
4. Manipulation of observation meterials.
5. Visual observations.

Each measurement was weighed against these criteria; man was considered "valuable" in space if three or more were involved in the measurement program and "useful" if one or two were satisfied (Figures 5-12 and 5-13). Results indicated that man could make a useful or valuable contribution to nearly 50% of the measurement programs in the R&D phase. In the operational phase, however, the role of man became less certain, as indicated by the significant number of "to-be-determined" judgments. The measurement programs requiring man were generally those involving highly complex instruments with selective pointing, or specific zero-g experiments requiring monitoring and controlling.

It should be noted that this analysis did not represent an exhaustive evaluation of the role of man. Other potential uses of man which capitalize on his natural ability, training, and specific skills as a scientist, observer, and operator, as well as those functions attendant to the maintenance of the spacecraft and its payload, require further study.

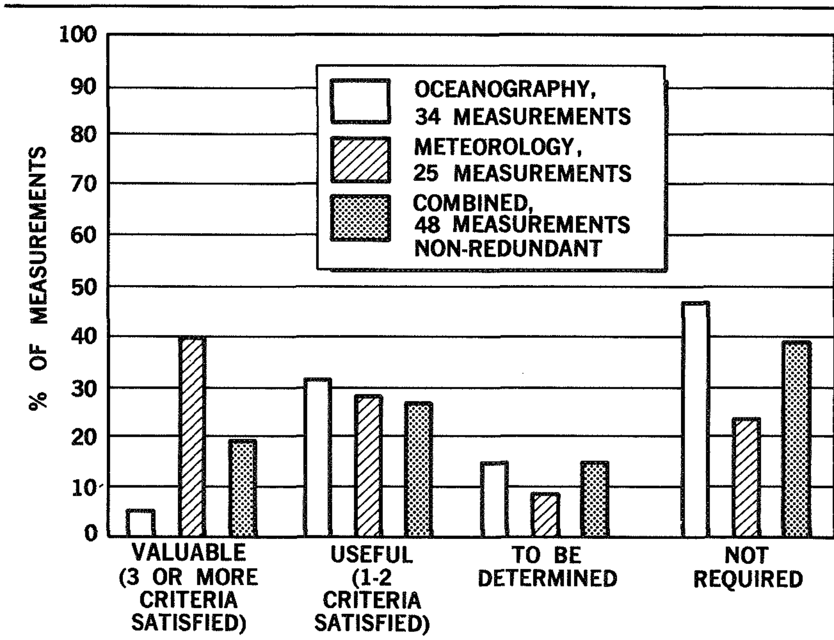

Figure 5-12. Manned Orbital Requirements-Research and Development Phase

5.6 ORBITAL OPERATION REQUIREMENTS

Analyses of orbital inclinations for various

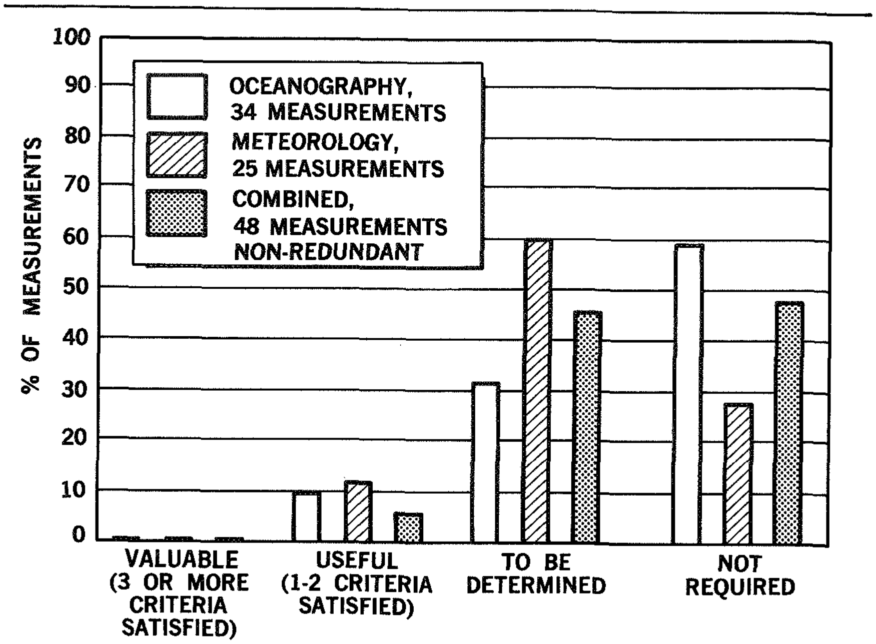

Figure 5-13. Manned Orbital Requirements-Operational Phase

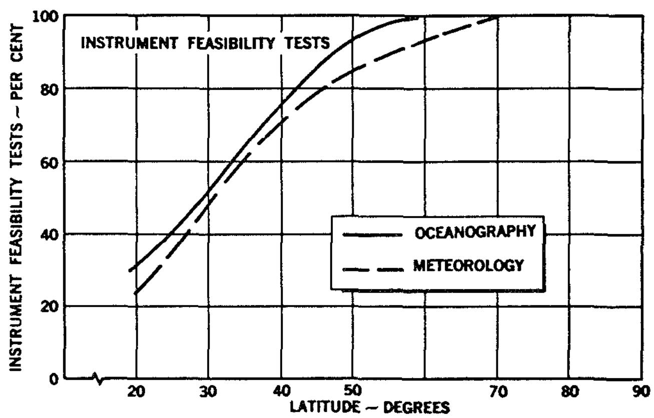

Figure 5-14. Latitude Requirements-Research and Development

R&D and operational activities (Figure 5-14) indicated that 50% of oceanography and meteorology instrument feasibility tests could be accomplished between 0° and 30° north and south latitude and all could be accomplished in a 70° orbit inclination. Figures 5-15 and 5-16 show the latitude coverage providing various degrees of measurement capability for short-range, extended-range and long-range prediction for two regions: the tropics and the mid-latitudes. Data requirements for both vary, but they are clearly a function of the length of time of the forecast period. When longer range forecasts are desired, higher latitude data is needed in the predictive model.

5.7 INSTRUMENT REQUIREMENTS

Examination of instruments required for the various measurement programs indicated that 25 generic classes would provide the basic data needed in the R&D phase of the program development activity.

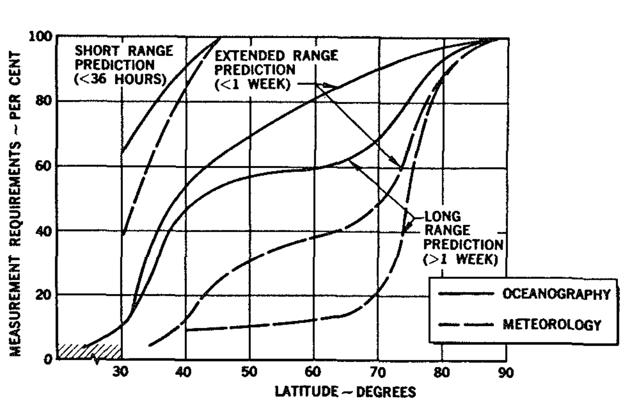

Figure 5-15. Latitude Required for Operational Requirements-Tropic Regions

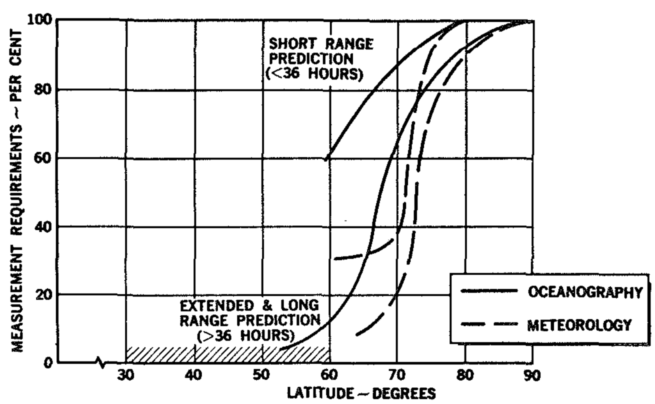

Figure 5-16. Latitude Required for Operational Requirements-Midlatitude Regions

Currently available or proposed instruments were examined to determine whether they provided the desired instrument capabilities and the measurement requirements. The prime source of data on existing and proposed instruments was the NASA-supplied lists from the Nimbus and Applications Technology Satellite programs and from the APS A and B Apollo Applications Program. Of the 25 required instruments, 20 could be identified in current or proposed NASA programs; 5 were new. Figure 5-17 summarizes the types and program sources for these instruments.

Instruments proposed for APS A and B programs would play a significant role in satisfying the oceanography and meteorology program requirements. If these programs did not materialize, a corresponding gap in equipment development would exist.

Section 6

SCOPE OF STUDY AND STUDY LIMITATIONS

The foregoing discussion has described the procedures followed in identifying orbital-research objectives in a logical and systematic manner. The study has examined the disciplines of oceanography and meteorology from the viewpoints of the research scientists and of other potential users of the information. Recommendations for specific classes of measurements have been made.

The study was limited to the examination of the oceans, the atmosphere, and their interaction. Coastal zones were included, but the freshwater or limnological zones were not. Also, the tidal influence of the sun and the moon on the atmosphere was not explored. Before a comprehensive plan for Earth-oriented research can be developed, these and other regions of Earth-centered observations should be analyzed. It can be anticipated that agricultural and forestry applications, geological surveys, and photogrammetric mapping activities would require many of the same types of sensing devices in orbit as found useful for oceanography and meteorology. Establishing the measurement commonalities among a multidisciplinary set of research objectives would undoubtedly suggest more efficient and effective orbital-research program plans.

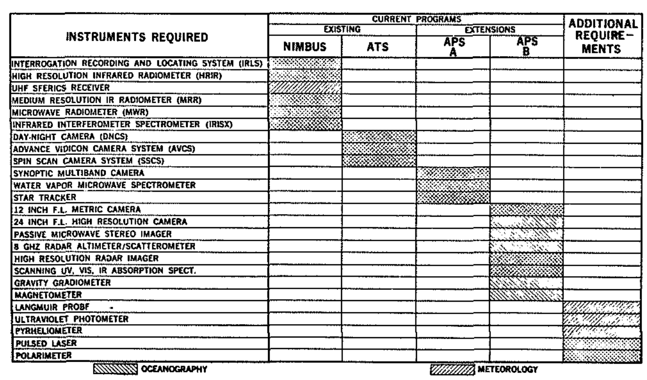

Figure 5-17. O&M Instrument Package Accommodation

Once a multidisciplinary orbital-research or experiment plan has been formulated, the remaining steps in the overall program planning can be accomplished: supporting R&D can be identified; design requirements for space laboratories and facilities can be specified; and the mission operations and ground support necessary can be defined. Hardware development times and costs will then provide a basis for the preparation of a realistic time-phased program plan. These steps remain to be taken.

The present study was further limited to the identification of observational requirements which were of value to oceanographic and meteorological research and which appeared to be potentially feasible from remote platforms. No attempt was made to assess the economic tradeoffs involved in determining the cost effectiveness of the various potential data-gathering platforms, (i. e., aircraft, surface vessels, or orbital facilities) although judgments were made regarding the most responsive type of measurement platform from an engineering or research standpoint.

Finally, the scheduling of orbital research requires an ordering of research objectives. This implies the assessment of priorities for the measurements as a function of the relative importance of the critical issues to which the measurements are directed. During the present study, the scientific contributors were asked for their judgments regarding the relative importance of the issues identified. There was generally universal agreement that both atmospheric and oceanographic pollution were the most important issues. Beyond this point, judgments differed. While it was beyond the scope of the present study to pursue the problem of priority assessment with the scientific community as a whole, it must be recognized that, unless a consensus can be derived by competent authority, future planning studies will be limited in their ability to establish the most significant and effective experiment plan.

Section 7

IMPLICATIONS FOR RESEARCH

The Oceanography and Meteorology Study found that a significant number of the measurements necessary to fulfill the study objectives can be implemented by a remote-observation program. For remote sensing of certain parameters, such as surface charge, bottom composition, and acoustic signature, an advance in technology is needed. The importance of these variables suggests that research might profitably be directed toward these areas.

Besides the instruments to implement the measurements program, other factors are required to completely synthesize the system. For example, one major objective of the meteorology program is the achievement of accurate, long-range weather forecasts. While capabilities exist today for 36-hour forecasts based upon simplified two-degree-of-freedom models with 500-km resolution, accurate 10- to 14-day forecasts require more complicated three-degree-of-freedom models, with input data accurate to a 5-km resolution level (Figure 7-1).

Development of more accurate long-range forecasting requires sensors capable of much finer resolution and requires more frequently sampled observations of the atmosphere. Coupled with these trends are requirements for advanced mathematical models capable of operating with increased fidelity in simulating the physical situation. Study of recent COSPAR reports indicates that major portions of the numerical models necessary in the simulation have been formulated but remain to be tested and verified. The refinement and validation of such mathematical models will be a continuing research need.

The trend in meteorology toward higher resolution and more frequent measurements and the advanced theoretical numerical models for weather forecasting makes an advance in computational facilities a more critical requirement. Analysis of these requirements indicates that, to achieve the desired automatic forecasting capability, an increase of many orders of magnitude in data-processing capacity over currently available systems will be required. Thus, data handling is a major and critical R&D area.

One measure of this, as shown in Figure 7-2, is an increase of 100 million over the requirement for computer operations per unit time found in current system capabilities. This increase represents the increased data-processing load in moving from the short-range forecasts with 500-km grid point resolution currently programmed, to the future requirement for long-range forecasts with 5-km resolution.

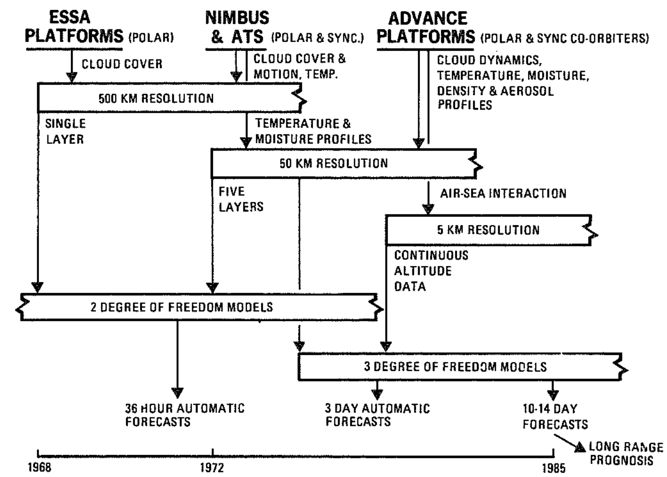

Figure 7-1. Meteorological System Evolution

Similar trends are found in oceanography. Analysis has shown that, for large-scale fisheries prediction and the generation of use-oriented information, the data-acquisition rate exceeds the stated capabilities of any current or contemplated observation platform. As mentioned previously, more fundamental to the problem of implementing a fisheries-prediction system is the formulation and verification of theoretical models of marine biological behavior. Expansion of applied-research activities can validate existing models and develop new ones, as required. These classes of research are very long range programs which can lead to vast increases in scientific understanding of very complex natural processes.

This study did not consider the economic implications of the research program necessary to fulfill the objectives identified by the systematic approach. It should also be noted that no current satellites in orbit directly support oceanography research objectives, although much of the meteorological data currently being gathered can be used in oceanographic research.

An example of the anticipated experiment program evolution foreseen for orbital oceanography and meteorology is documented in Volume II, Appendix A. Certain characteristics can be seen in the total measurement requirements, which provide insight into the expected role of a manned space platform during the early research phase. Towards this end, measurement requirements were suggested for areas (1) where manned participation is valuable or useful and (2) where orbital platforms or a combination of space and other platforms is needed. This subset of total requirements includes such observation types as sea color, turbidity, and bioluminescence; storm tracking, air, and cloud motion; sea-surface temperature; surface, and airborne objects; vertical soundings of temperature, pressures, moisture, and winds; gaseous, liquid and solid composition of the atmosphere; and electrical discharges.

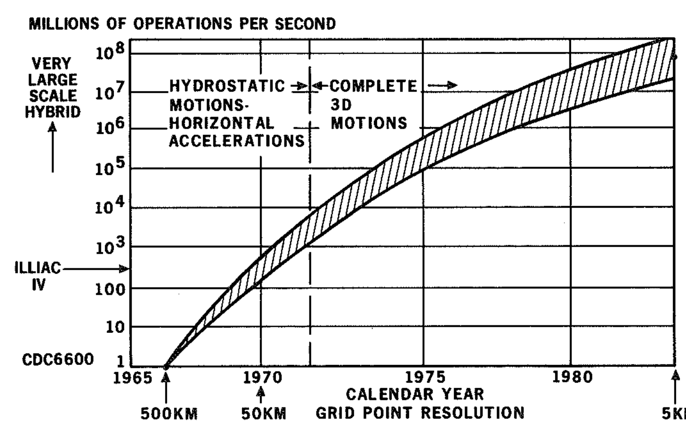

Figure 7-2. Computer Requirements for Automatic Weather Prediction

Study of the instrument-development requirements has indicated that initial emphasis can most profitably be placed on the development of cameras and IR radiometers. These, in turn, are followed by spectrometers, microwave radiometers, radars, and groups of these instruments functioning together. Nighttime coverage becomes practical as radiometers and low-light-level camera systems are introduced. Spectrometers permit temperature- and moisture-profile observations, while microwave radiometers and radars allow sensing of surface and rainfall conditions.

The measuring instruments finally used in orbital research will include the more advanced and complex sensors of the equipment grouping. Also, the functional activities involved in performing these measurements can be anticipated to be particularly complicated during the early research phase, considering requirements for simultaneously making observations and ground truth tests. Man's role as a researcher, observer, and instrument operator during this critical early research phase will be particularly important. His natural ability, coupled with training and specific skills, will address such orbital activities as critical instrument adjustments, coordinated experimental procedures where several parties will be in voice contact with each other, on-board handling of important data, observational techniques, and early interpretation of results of individual research experiments. When these scientific duties are coupled with other required on-board supporting activities, such as maintenance and repair, the synergistic observational capability of a flexible manned orbital-research facility will be fully realized.

Section 8

SUGGESTED ADDITIONAL EFFORT

This study explored the areas of oceanography and meteorology research and identified elements of a long-range experiment plan which would profit by the use of space platforms, utilizing the capability provided by manned operations. In doing so, this study has examined a significant portion of the sun-Earth coupled system. To identify completely all sun-Earth interactions and relationships, however, the study should be expanded to cover other related areas of interest such as the limnological zone (including land, rivers, lakes, and streams) and lithospheric phenomena. From this extended base, the total Earth-oriented program of oceanographic and meteorological research could be synthesized with balanced requirements, mission loads, and specific R&D goals.

In addition to a completed study of the land-sea-air interface, the following areas for further activity are recommended:

1. Expansion of the systematic approach for the identification of research objectives to include other Earth-oriented research areas: agriculture, forestry, geography, geology, and hydrology.
2. Delineation of general mission-planning requirements, promising options, and measurement tradeoffs.
    - A. Identification of major factors influencing operation and configuration design.
    - B. Examination of data-handling needs and system impact on ground facilities.
    - C. Description of mission mode alternatives, day/night observation targeting, and unique research-oriented observational opportunities.
    - D. Determination of economic tradeoffs between alternative data collection methods.
3. Development of a time-phased plan, including engineering estimates of costs and schedules, showing program alternatives, major R&D milestones, and design-decision points.

4. Development of a theoretical base through observation of remotely sensed data which can be used to infer parameters of specific interest to users.
5. Identification of critical R&D areas.
   A. Examination of the needs for key theoretical studies and long-term investigations necessary for model development.
   B. Definition of the pacing experiments requiring zero-g or orbital observations and investigations of technological advance necessary to implement the ultimate data-management requirements.

In summary, the Oceanography and Meteorology Study has been an exploratory effort to define systematically those orbital measurement requirements which would most directly serve the needs of the scientific community and potential using agencies. The design and operation of manned and unmanned space vehicles appears to be well within current technology. To be effectively utilized, however, such vehicles must be responsive to user needs. It is hoped that the effort described in these documents will help provide some insight into an analytic approach which translates user objectives into measurement plans.

REFERENCES

1. The National Space Program--Its Values and Benefits, Staff Study for the Subcommittee on NASA Oversight, U.S. Government Printing Office, Washington, 1967.

2. The Orbital Astronomy Support Facility Study Final Report: Technical Summary. Douglas Report No. DAC-58141, April 1968.

3. The Orbital Astronomy Support Facility Study Final Report. Task A: Orbital Astronomy Research Requirements. Part 1: The Baseline Astronomy Research Program. Part 2: A Methodology for Systematic Identification of Candidate Space Astronomy Observations. Douglas Report No. DAC-58142, April 1968.

4. The Orbital Astronomy Support Facility Study Final Report. Task B: Instruments for Orbital Astronomy. Douglas Report No. DAC-58143, April 1968.

5. The Orbital Astronomy Support Facility Study Final Report. Task C: Orbital Astronomy Support Facility Concepts. Douglas Report No. DAC-58144, April 1968.

6. The Orbital Astronomy Support Facility Study Final Report: Research and Technology Implications for Orbital Astronomy. Douglas Report No. DAC-58145, April 1968.

7. S-IVB Station Module Study: Technical Summary. Douglas Report No. DAC-56554, November 1967.

8. ORL Experiment Program, Vol. B, Part III, Oceanography/Marine Technology. IBM Corporation, Rockville, Maryland, 21 February 1966.

10. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential, Final Report. Douglas Report No. SM-48821, January 1966.

11. Report on the Development of the Manned Orbital Research Laboratory (MORL) System Utilization Potential, Summary Report. Douglas Report No. SM-48822, January 1966.

12. The Needs and Requirements for a Manned Space Station, Vol. 4--Meteorology. Prepared by the Panel on Meteorology of the Space Station Requirement Steering Committee, 15 November 1966.

13. G. Ohring. Meteorological Experiments for Manned Earth Orbiting Missions, Final Report. GCA Corporation (Bedford, Massachusetts) No. 66-1[illegible]-N, March 1966.

14. G. Cato. Manned Earth Orbiting Missions. Electro-Optical Systems, Inc., Pasadena, California. Prepared under Contract No. NASw-1291, March 1966.

15. Annual Report, Spacecraft Oceanography Project, 1 October 1965--1 September 1966. U.S. Naval Oceanographic Office, Washington, D.C.

16. Annual Report, Spacecraft Oceanography Project, 1 October 1965--1 September 1966, Annex A: A Review of Achievements in Remote Sensing for Oceanography. U.S. Naval Oceanographic Office, Washington, D.C.

17. V.E. Suomi. Observing the Atmosphere--Some Possibilities. Report of the Study Conference on the Global Atmospheric Research Programme (GARP), Appendix VII, ICSU/IWGG, Committee on Atmospheric Sciences, COSPAR, and World Meteorological Organization, July 1967.

18. United States Activities in Spacecraft Oceanography. The National Council on Marine Resources and Engineering Development, Washington, D. C. October 1, 1967.

19. C. W. Churchman, R. L. Ackoff, and E. L. Arnoff. Introduction to Operations Research. John Wiley and Sons, 1967.

20. Fritz Zwicky. Morphology of Propulsive Power. Monographs on Morphological Research No. 1, Society for Morphological Research, Pasadena, California, 1962.

21. O. Helmer and N. Rescher. The Epistemology of the Inexact Sciences. The RAND Corporation, February, 1960.

DOUGLAS

MISSILE & SPACE SYSTEMS DIVISION/SPACE SYSTEMS CENTER
5301 BOLSA AVENUE, HUNTINGTON BEACH, CALIFORNIA
A DIVISION OF DOUGLAS AIRCRAFT COMPANY, INC.